ISSN 0259-2517

Mangosteen cultivation

FAO
PLANT
PRODUCTION
AND PROTECTION
PAPER

129

Food
and
Agriculture
Organization
of
the
United
Nations

Mangosteen cultivation

FAO
PLANT
PRODUCTION
AND PROTECTION
PAPER

129

Othman Yaacob
Universiti Pertanian Malaysia
Selangor, Malaysia
and
H.D. Tindall
Emeritus Professor
Cranfield University
Bedford, United Kingdom

Technical and Scientific Coordinators
U.G. Menini and **A. Hodder**
Horticultural Crops Group
FAO Plant Production and Protection Division

Food
and
Agriculture
Organization
of
the
United
Nations

FIAT PANIS

Rome, 1995

The designations employed and the presentation of material in this publication do not imply the expression of any opinion whatsoever on the part of the Food and Agriculture Organization of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

M-11
ISBN 92-5-103459-1

Frontispiece: MANGOSTEEN (*Garcinia mangostana* L.)
Source: Fleurs, fruits et feuillages choisis de la flore et de la pomone de l'île de Java. Peints d'après nature par Madame Berthe Hoola Van Nooten. Ouvrage dédié à sa Majesté la Reine de Hollande.
Published in 1863 by Emile Tarlier, Brussels, Belgium.

CONTENTS

INTRODUCTION

Among the cultivated tropical tree fruits, the mangosteen (*Garcinia mangostana* L.), which was named after the French explorer Laurent Garcin (1683-1751), is probably one of the most limited in geographical origin and distribution. A native of South-east Asia, this species has remained localised mainly in its native habitat; this is probably due to its rather specialised ecological requirements. In addition, establishment is relatively difficult, since seedlings are slow to grow, even in their natural environment.

Mangosteen trees grow naturally as understorey plants in forest communities. In cultivation, shading is therefore beneficial during the first 4 to 5 years of early growth and this is often provided by other trees which are normally grown in mixed holdings.

Traditionally, the mangosteen has been propagated by seeds. These are produced apomictically, without fertilization, and they therefore produce seedlings which, when fully grown, are identical to the parent tree. The establishment of mangosteen as a cultivated fruit followed the expansion of population throughout the various areas of South-east Asia.

Mangosteen fruits weigh from 70-150g and they are generally considered to be one of the finest flavoured fruits in the world, outranking all other tropical fruits; the mangosteen has therefore justly earned the popular title of 'Queen of Fruits'.

Although the popularity of the mangosteen is consistently increasing, international trade still remains negligible, although fruits exported from South-east Asia are increasingly found in European markets and fruits from Central America are exported to the USA.

In recent years, the mangosteen has been subjected to renewed interest in the international markets and attempts are now being made to study the fruit in greater detail. Mangosteen production is not normally included in statistical data from Indonesia, Malaysia and other countries in Asia and it is generally listed as a tree fruit grown to a limited extent.

In South-east Asia, the economics of mangosteen production have not been accurately estimated although farmers are known to earn extra

income from sales of fruits which are in excess of their own requirements. A few large-scale mangosteen growers have become established in the region and intensive research has been undertaken, particularly on aspects of propagation and processing, mainly in Thailand, Malaysia and Indonesia. Published information on some aspects of production and processing is slowly becoming available, but most of these sources of data are written in Thai, Indonesian or Malaysian languages. Very few articles or papers on mangosteen production and research appear in international journals of abstracts.

In recent years, however, international markets have shown a renewed interest in the mangosteen and further attempts are now being made to study this crop in more detail. The medicinal uses of some mangosteen by-products have also been investigated in recent years.

The information presented in this manual has been obtained from various sources, including published papers in English and vernacular languages and personal discussions with officials of agricultural organizations and progressive growers, predominantly from Malaysia and Thailand.

Othman Yaacob
Soil Science Department
Faculty of Agriculture
Universiti Pertanian Malaysia
43400 Serdang
Selangor
Malaysia

H.D. Tindall
Emeritus Professor
Cranfield University
Cranfield
Bedford
United Kingdom

ACKNOWLEDGEMENTS

The senior author acknowledges the valuable assistance received from numerous persons and organizations, including government officials and private growers throughout South-east Asia, and particularly those in Malaysia and Thailand, in the preparation of this Manual on behalf of the FAO Plant Production and Protection Division.

Particular thanks are due to Dr. U.G. Menini and Dr. A. Hodder, the Technical and Scientific Coordinators for their support, also the Fruit Research Division of the Malaysian Agricultural Research and Development Institute (MARDI), the Federal Land Development Authority (FELDA), the ASEAN Food Handling Bureau (AFHB), various State Agricultural Stations in Malaysia, the Department of Agricultural Extension, Bangkok and Southern Thailand, Dr. Noparat Bamroongrugsa from the Prince of Songkla University, Pattani Campus, the Thailand Institute of Industrial Scientific and Technology Research (TISTR), and Mr. Nivat Pontchour, who represents one of the most successful mangosteen growers from eastern Thailand, for his most helpful assistance on many occasions.

Sincere appreciation is also extended to Miss Salmah Kassim, who was responsible for processing the original manuscript and to the Soil Science Department, Universiti Pertanian Malaysia for the use of various facilities.

Othman Yaacob

The assistance of the Librarian and staff of the Library of Silsoe College, Cranfield University, was most helpful and the valuable contribution of Patricia Woodland in processing the final manuscript has been particularly appreciated. The photograph of the drawing featured in the Frontispiece was kindly provided by Pierre Martin-Prevel of CIRAD/FLHOR, Montpellier, France.

H.D. Tindall

LIST OF TABLES

LIST OF FIGURES

LIST OF PHOTOGRAPHS

Frontispiece: Botanical drawing of mangosteen, dated 1863

SECTION 1. THE PLANT AND THE ENVIRONMENT

CHAPTER 1. HISTORY, AREA OF ORIGIN AND DISTRIBUTION

Historical Background

The mangosteen is presumed to have originated in South-east Asia, possibly in the Indonesian region, and was known in the western world as early as 1631. Trees are found growing in the wild on a wide range of soil types and locations. Establishment on a relatively wide scale followed the increase of human settlements during the early days of population expansion in South-east Asia. Later, early European travellers, explorers or plant collectors such as Mjobery (Swedish), Fairchild (English), Laurent Garcin (French) and Popenoe (American) recorded descriptions of this fruit in their journals and writings.

The mangosteen (*Garcinia mangostana* L.) was named after the French explorer Laurent Garcin (1683-1751) and has been in cultivation for a considerable time in various parts of the humid tropics. It has, however, like many other minor tropical fruits, been referred to in various 19th Century publications as being a tropical fruit tree of mainly botanical interest.

Area of Origin and Distribution

Among the cultivated tropical tree fruits, the mangosteen is probably one of the most localised in relation to its centre of origin, habitat and area of cultivation. A native of South-east Asia, the tree has remained mainly centred around its original habitat, possibly partly due to the fact that the fruit, although encased in a thick shell, remains edible for a very limited period. In addition, the seeds are recalcitrant, and quickly lose their viability. The mangosteen is found growing in a natural state in the Malay Peninsula, Myanmar (formerly Burma), Thailand, Cambodia, Vietnam, the Sunda Islands and the Moluccas and, in cultivation, it is normally grown in South-east Asia in mixed horticultural holdings, locally called *dusuns* in Malaysia and Indonesia (Plate 1).

Plate 1. Mangosteen grown in a mixed horticultural holding

The exact origin of the mangosteen has not been fully established but a recent theory, proposed by Zeven and de Wet (1982) is that it is derived from *G. silvestris* Boerl., a species found growing in both Malaysia and India.

The latest definitive study by Richards (1960b) on the origin of the mangosteen has, however, indicated that Peninsular Malaysia was probably the area of origin, the original parent having possibly arisen as a hybrid between *G. hombroniana* and *G. malaccensis* (see section on Genetics).

Cultivation in South-east Asia has been mainly limited to the area of origin which extends from Indonesia eastwards to New Guinea and Mindanao in the Philippines and north, via Malaysia, into the southern parts of Thailand, Burma, Vietnam, the Philippines and Cambodia. It appears likely that the mangosteen was first domesticated in Thailand or Burma (Corner, 1952). Only during the last two centuries has the crop spread to other tropical areas, including the Ivory Coast, Madagascar, Sri Lanka, South India, China, Brazil, and parts of Queensland, Australia. It has also been planted in Costa Rica, Puerto Rico, Dominica, Jamaica and Panama (Almeyda and Martin, 1976) and small plantations have been established in Hawaii, Honduras, Guatemala, southern Florida and Cuba (Winters, 1953; Campbell, 1967).

Details of the periods during which introductions of mangosteen were made into tropical countries where it is now established are limited but it appears that trees were introduced into Sri Lanka in about 1800. These were possibly obtained from India where trees are known to have been grown in Madras State during the 18th Century (Krishnamurthi and Rao, 1962). Mangosteens are recorded as being grown in the West Indies before 1855 (Popenoe, 1928); trees introduced into Trinidad, from the Royal Botanic Gardens, Kew, England in 1850-1860 fruited in 1875. Records indicate that seeds were sent to Queensland, Australia at about the same time; it is not known if this introduction was successful but later, and probably successful, introductions were obtained from Java (Stephens, 1935). A more recent introduction was made into the Malagasy Republic in 1901 (Moreuil, 1971).

Details of the early distribution of mangosteen have also been given by Hume (1950) and Cox (1976). During the 1960-1980 period mangosteen was introduced into the Hainan and Xishuanbana provinces of tropical China from Malaysia, Thailand, Indonesia and Sri Lanka but yields per individual tree are reported to be low, compared with those of Malaysia or Thailand, although the quality of fruit is equally good.

Figure 1. The area of origin (circled) of the mangosteen and possible geographical distribution
(after Pijpers et al. (1986))

CHAPTER 2. ECONOMIC IMPORTANCE, NUTRITIONAL VALUE AND USE

Economic Importance

The mangosteen is now gaining increased recognition in the international market and recent demands for exported fruit have prompted growers to consider this crop with renewed interest. Intensive research has recently been undertaken, especially on propagation and processing, in Thailand, Malaysia and Indonesia. The fresh fruits command a high price in international markets such as those in Hong Kong, Japan and Europe.

In spite of the popularity of exported fruit, the international trade is still relatively negligible, although fruits are sometimes found in distant markets in Europe and the USA. The European markets are supplied from countries in South-east Asia and those in the USA from Central America. The mangosteen is not included in statistical data from Indonesia, Malaysia and other producing countries in Asia and is generally recorded as a minor fruit, grown in limited areas.

No annual production data are available for Malaysia, but the area under production appears to have declined annually, and rapidly, from 4300ha in 1970 to 1240ha in 1980 (Chan et al., 1982). Because of the recent renewed interest in the fruit there has, however, been a small increase in the area under mangosteen grown as a plantation crop both in Thailand and Malaysia. In Malaysia, since 1985, nearly 30ha have been planted with this crop by the Federal Land Development Authority (FELDA), 200ha by a private overseas-based organization and about 25ha by the Malaysian Agricultural Research Institute (MARDI). All of these developments are large scale plantings.

In South-east Asia, the economics of mangosteen production have not been accurately determined, although farmers in many producing countries are known to earn an income from the selling of fruits which are surplus to household requirements. The present total production consists of the produce from various small-scale farmers from the traditional *dusun* system, combined with that of medium-sized orchards.

There is now an increasing interest in the specialized production of mangosteen on a commercial scale. For example, in the eastern and southern provinces of Thailand, a few medium-sized to large-scale growers have recently become established, exporting mangosteens to various parts of Europe and Japan. Over the past 15 years one grower has largely replaced his durian plantation with mangosteen trees and, in 1986, almost 80 tonnes of good quality fruits were exported. The value of first grade mangosteen fruits can be quite substantial when prices are at a high level.

Joint ventures with overseas countries, with the objective of producing mangosteen for export to Europe, the USA and Japan are being introduced by countries such as Malaysia. Such enterprises have been made possible by the introduction of fast-freezing techniques, in which the fruits are stored in temperatures of -18°C.

The economic importance of the mangosteen, both for domestic use and export, is small but it is gradually increasing as domestic and overseas demand increases. Thailand is the highest producer; 62,000t of fruit were harvested in 1981, from an area variously estimated to range from 8,000ha to 12,000ha; most of the production coming from the eastern and southern provinces. Later reports indicate that, in 1986, the production from Thailand was 68,700t (Visetbhakdi, 1988) from an area of approximately 15,000ha and Malaysian production was reported to be 27,000t in 1987 from a production area of 2,200ha. Murray (1990) has reported that, in 1987, the volume of production in the Philippines was 2,270t, from an area of 1,130ha, an average yield of approximately 2t per ha; this was a significant increase over the 1981 production which was 700t from a planted area of 400ha. The above figures do not make allowance for newly planted and non-bearing trees which may take 10-12 years to become productive.

Estimated production figures for mangosteen, from several countries, are given in Table 1.

Table 1. Production, mean annual yield and exports of mangosteen from Indonesia, Malaysia, Thailand and the Philippines.

	Indonesia	Malaysia	Thailand	The Philippines
Production (in '000t)	--	27	67	2
Mean Annual Yield (per ha)	--	12.9	5.2	1.8
Export Value (US$x1000)	261	204	5645	--

Source: Verheij (1991)

Economic assessments of the costs and returns associated with mangosteen orchard establishment and maintenance are almost non-existent but the following table, of unrecorded origin, serves as an indication of the estimated relative costs of production and the returns which could be expected.

Table 2. Estimated costs and returns for mangosteen cultivation on a per hectare basis

Year	0	1	2	3	4 to 5	6 to 8	9 to 12	13 and after
Land clearing and preparation	950							
Planting	850	115						
Other development costs	400	75	75	75	150	150	175	175
Manuring and field maintenance		475	505	500	1045	1165	1725	1520
Harvesting and handling					60	740	1830	2500
Total costs	2200	665	580	575	1255	2055	3730	4195
Marketable Yield No/ha					2500	30000	75000	110000
Estimated wholesale price $/fruit					.11	.11	.11	.11
Gross Revenue ($)	0	0	0	0	275	3300	8250	12100
Net income (with employed labour) $	-2200	-665	0580	0575	-980	1245	4520	7905

Nutritional Value

Mangosteen fruit weight varies between 75-120g and fruits contain 2-3 well developed seeds. About 25-30 percent of the fruit consists of the edible pulp or aril; the components of the pulp are: 19.8 percent soluble solids, 4.3 percent reducing sugar, 17.5 percent total sugar, 0.5 percent protein, 0.23 percent ash and 0.49 percent acid. The estimated nutritive values of mangosteen fruits grown in various geographical areas are shown in Table 3.

Table 3. The nutritive value of fresh mangosteen fruits (per 100g), compiled from various sources.

	Source/Reference Country			
Fractions of the aril	Philippines (Food and Nutrition Center, 1968)	Sri Lanka (Vaz, 1973)	Thailand (Min. Health, Thailand, 1987)	Malaysia (Nat. Sub-Committee on Protein, 1988)
Edible portion (%)	--	70.0	--	--
Moisture (%)	79.7	82.6	79.0	87.6
Food energy (kcal)	76	--	--	34.0
Protein (g)	0.7	0.60	0.50	0.6
Fat (g)	0.8	--	Nil	1.0
Total carbohydrate(g)	18.6	16.5	19.8	5.6
Fibre (g)	1.3	--	0.3	5.1
Ash (g)	0.2	--	--	0.1
Ca (mg)	18.0	5.7	11.0	7.0
P (mg)	11.0	9.4	17.0	13.0
K (mg)	--	--	--	--
Fe (mg)	0.3	--	0.90	1.0
Vitamins:				
A (carotene) (IU)	0.0	--	14	--
B_1 (thiamin) (mg)	0.06	--	--	0.03
B_2 (riboflavin) (mg)	0.01	--	--	0.03
B_5 (niacin) (mg)	0.04	--	--	0.3
C (ascorbic acid) (mg)	2.00	--	66	4.2

(NB. The variation observed in some of the above results may be due to the different analytical bases adopted by nutritionists in the various countries).

Additional data, from Guangzhou, southern China, have also been published by Chau Kay-Ming (1990) and are given in Table 4.

Plate 2. Mature mangosteen trees showing the growth habit of tree

Table 4. Composition of mangosteen fruits

Component	Per 100g of aril
Water	79.2
Protein (g)	0.5
Carbohydrates (g)	19.8
Citric acid (g)	0.63
Fibres (g)	0.3
Calcium (mg)	11.0
Phosphorus (mg)	17.0
Iron (mg)	0.9
Vitamin A (carotene) (IU)	14.0
Vitamin B (thiamin) (mg)	0.09
Vitamin B_2 (riboflavin) (mg)	0.06
Vitamin B_5 (niacin) (mg)	0.1
Vitamin C (mg)	66

Source: Chau Kay-Ming (1990)

The data indicate that the pulp of mangosteen fruits contain a high level of moisture and carbohydrates, mostly in the form of sugars. Minerals, particularly calcium and phosphorus, occur at relatively high levels but the vitamin content, with the possible exception of ascorbic acid, is generally low.

Use

Constructional and amenity

The dark-red timber of mangosteen is heavy, coarse and very durable and, when available, it is used for cabinet-making, building materials, fencing and to make rice pestles or pounders (IBPGR, 1986). The heart wood of the trunk is dark brown and produces valuable timber for constructing furniture. It is also used by skilled Indonesian craftsmen to make souvenirs depicting the shape and size of the fruit. The tree is ideal for use in amenity horticulture as an ornamental tree which provides shade and does not undermine sidewalks or building foundations through the penetration of its roots. The tree has a symmetrical, cylindrical shape, with a large number of lateral branches and leaves of brilliant green which create an attractive sight in botanical gardens and parks (Plate 2).

Dyes

The pericarp contains pectin, tannins, resins and a yellow latex. In China, pericarp extracts are used for tanning and dyeing leather black and the yellow latex from related *Garcinia* species is used used as a dye in Thailand, Malaysia and Indonesia.

Medicinal constituents

An increasing level of research has recently been undertaken on the chemical content of the mangosteen pericarp which has been found to contain valuable compounds used in medicines and, to a certain extent, as anti-bacterial agents. Sen et al. (1980, 1982) have found that the pericarp contains five polyoxygenated xanthones, including mangostin 4, β-mangostin, nor-mangostin and gartanin.

A derivative of mangostin has been found to be a central nervous system depressant and it may also cause a rise in blood pressure. Many of the xanthones found in the fruit pericarp, particularly mangostin, have significant anti-inflamatory properties at doses of 50mg/kg; anti-ulcer activity has also been demonstrated (Bennett and Lee, 1989). The xanthone content in the pericarp and the number of compounds synthesized increases as fruit-ripening proceeds (Nagy and Shaw, 1980). The presence of anthocyanins such as cyanidin-3-sophoroside and cyanidin-3-glucoside, both of which are responsible for the red colouring of the mangosteen rind, have been confirmed by Du and Francis (1977).

In India, the fruit pericarp of mangosteen is used in Ayurvedic medicine in the treatment of inflammation and diarrhoea; the dry, pulverized pericarp is also used in a decoction as an astringent for treating dysentery. An infusion made from the leaves has also been used for treating wounds. Two new xanthones have recently been isolated from the dried pericarp and have been described (Balasubramanian and Rajagopalan, 1988). The fruit pericarp is also used in Thai medicine for healing skin infections and for the relief of diarrhoea (Pongboonrawd, 1976)

An extensive summary of recent work on the identification of the many xanthones which occur in species of the family Guttiferae has been given

by Bennett and Lee (1989) who have also listed the various pharmacological properties of xanthones, including those which occur in mangosteen.

<u>Fresh fruits</u>

The mangosteen fruit is always best eaten as a fresh fruit. The method of preparation is to cut carefully across the central part of the woody layer, removing the thick skin without touching the white aril. Care must be taken to prevent the resins or tannins exuded from the cut pericarp coming into contact with the fruit segments. When the segments of the aril are exposed, they can be removed with a fork. The seeds are also edible, after they have been boiled in water.

<u>Preserved fruits</u>

Mangosteen fruits can also be preserved; the more acid types are generally preferred. The segments of the pulp are extracted from the ripe fruits and are immersed in a syrup consisting of sugar and water in a 1:2 ratio to prevent discolouration. The syrup is then drained off and the segments are placed in a bottle of fresh syrup prepared from equal quantities of sugar and water. After all the air has been released, the bottle is half-sealed, sterilized in boiling water for 25 minutes and is then sealed completely. Bottled and other preserved forms of mangosteen fruits are available in local markets in southern Thailand and the Philippines; both the pulp and seeds are boiled in sugar solution to make a preserve (Crisotomo, 1977).

Flavoured drinks, candy and jams are also prepared from the mangosteen aril for domestic use. Techniques have been developed by Siddappa and Bhatia (1954) for the production of juices, jelly, syrups and canned fruit segments. Much of the piquant aroma of mangosteen is normally lost during processing and a satisfactory method of conserving the flavour of the processed product needs to be developed.

<u>Irradiated fruits</u>

Irradiated mangosteen fruits have been investigated by Avadhani (1984) who found that fruits retained their quality when irradiated with doses of

25-200krad gamma rays. This treatment appears to have no practical relevance, at the present time, due to the high level of preservation of the fruits under normal storage conditions and even under quick freezing treatments.

Plate 3. Preparation of fresh fruits for consumption

CHAPTER 3. BOTANY, PHYSIOLOGY AND GENETICS

Botany

Nomenclature and taxonomy

The mangosteen, *Garcinia mangostana* L., which was earlier known as *Mangostana garcinia* Gaertner, belongs to the family Guttiferae which includes about 35 genera and over 800 species in the tropics of both hemispheres. Of these, about 9 genera include 86 species of fruit trees. The family is represented in the South-east Asian region by 5 genera and about 50 species. *Garcinia* may be considered to be a type genus within this family which also includes *Mammea*, a genus of some economic importance which is represented by the mammy apple or mammy, *M. americana* L.

In South-east Asia, the mangosteen is known by many vernacular names: *manggis* in Indonesia and Malaysia; sometimes as *settor, mesetor, semetah* or *sementah* in Malaysia; *manggustan,* or *manggis* in the Philippines; *mongkhut* in Cambodia; *mangkhud* in Laos; *dodol* or *mang-khut* in Thailand and *cay mang cut* in Vietnam; the Tamil name is *mangustai*. In French it is called mangostanier, mangoustanier, mangouste or mangostier; mangostan in Spanish; mangostane in German; mangoestan or manggis in Dutch, and mangostao, mangosta or mangusta in Portugese (Ochse et al., 1961).

Related species

Garcinia L. is a large genus with nearly 400 species, many of which are found growing on the island of Borneo. These probably include *G. dulcis* (Roxb.) Kunz., which is native to the Philippines and Indonesia where the yellow or brown fruits, which are high in vitamin C, 5cm in diameter and with a sweet taste, are widely used and are known as *mundu* in Indonesia and Malaysia, *gourka* or *ma-phut* in Thailand and *baniti* in the Philippines (IBPGR, 1986). *G. dulcis* is very similar to *G. xanthochymus* Hook. f. ex T. Anderson, which originated in India and is cultivated in Malaysia; the fruits are egg-shaped, yellow and juicy with a good flavour. *G. prainiana*

King, *G. cowa* Roxb. and *G. atroviridis* Griffith ex T. Anderson are cultivated in various parts of South-east Asia for their fruits.

The flowers of *G. atroviridis* are reddish and the large fruits are sour; the fully grown but green fruits are sliced, dried and used as a seasoning or sour relish, locally called *asam gelugur* in northern Malaysia (Halijah Ibrahim, 1989). The yellow latex from *G. hanburyi* Hook. f. is used as a dye in Thailand, Malaysia and Indonesia and *G. cambogia* Desrouss. from India is a source of gamboge, this is a yellow dye obtained from the resin which exudes from incisions made in the bark (Purseglove, 1972). *G. cambogia*, locally known as *goraka*, has a larger fruit than the mangosteen; the red or yellow skin is smooth and deeply indented. The large seeds are surrounded by an acidic pulp which can be preserved by sun-drying. The seeds contain 30% of edible fat (FAO, 1990).

In countries other than those in South-east Asia, species such as *Garcinia dulcis* and *G. livingstonei* are cultivated. *G. livingstonei* is native to East Africa and is well adapted to growing in Florida but the fruit is of only moderate quality (Hume, 1947). A description of this species has been published by the Citrus and Subtropical Research Institute (1976). The fruit is an orange-red fleshy berry with 1-5 seeds. *G. xanthochymus* was established in the Malagasy Republic and was also found to be well adapted to climatic conditions in Queensland, Australia (Stephens, 1935). It appears possible that, due to their relatively well-developed root systems, these three species could be useful as rootstocks for mangosteen scions.

The closest relative to the true mangosteen is probably *G. hombroniana* Pierre (Plate 4) which was named after the French physician and explorer J.B. Hombron. This species has been found growing in remote areas of Penang, the Nicobar Islands, Sabah and Kalimantan, Indonesia. It is known in Malaysia as the forest mangosteen or *manggis hutan* or *bruas* (Whitmore, 1973). Another closely related species is *G. malaccensis* T. Anderson which is also indigenous to Malaysia (Verheij, 1991).

Plate 4. *Garcinia hombroniana* Pierre, the forest mangosteen

Other species of *Garcinia*, the fruits of which have been recorded as being consumed locally in various areas include:

> *G. bancana* Miq. (*Kelabang* - Malaysia); *G. barrettiana* Wester. (*Kadis* - Philippines); *G. benthami* Pierre (Malaysia); *G. binucao* (Blanco) Choisy. (*Binukao* - East India to Philippines); *G. cambogia* Desrouss. (*Banti, Aradal, Hila, Goraka* - India); *G. cochinchinensis* (Lour.) Choisy. (Indochina); *G. cornea* L. (*Kirasa* - Malaysia, Burma); *G. cumingiana* Pierre (*Malaba* - Philippines); *G. delpyana* Pierre (*Trameng* - Indochina); *G. dioica* Blume (*Tjeuri* - Indonesia); *G. globulosa* Ridley (*Kandis* - Malaysia); *G. griffithii* T. Anderson (*Kandis gajah* - Malaysia); *G. indica* Choisy. (*Kokan, Ktambi* - Tropical Asia); *G. lateriflora* Blume (*Kariis, Djawura* - Philippines, Java); *G. macrophylla* Miq. (*Selapan* - Sumatra); *G. mooreana* Wester. (*Bunag* - Philippines); *G. multiflora* Champ. (*Bira tai* - Laos, Vietnam); *G. nigrolineata* T. Anderson; *G. oliveri* Pierre (*Tromeng* - Indochina); *G. paniculata* Roxb. (*Bubi-kowa* - Bengal to E. Himalayas); *G. parvifolia* Miq.; *G. planchonii* Pierre (Indochina); *G. tinctoria* (DC.) W.F. Wright (*Gamboge tree, Matau* - S. India, Malaysia);

G. vidalii Merr., *G. vilersiana* Pierre. (*Prahout, Vang nhura* - Cambodia, Laos, S. Vietnam); *G. venulosa* (Blanco) Choisy (Usher, 1974).

Morphology

Tree characteristics

The mangosteen is one of the slowest-growing of the tropical tree fruits but it is also one of the longest living. Seedling trees normally require from 10-15 years to fruiting. The mangosteen is a dioecious evergreen tree, 6-25m high, with a straight trunk, up to 25-35cm in diameter and symmetrically arranged branches which form a regular, pyramidal-shaped crown. The bark is often dark brown or almost black, rugose, with a tendency to flake. The evenly-shaped and dense, leafy crown makes it a valuable shade tree (Plate 2). A yellow type of latex or resin is present in all the main tissues of the tree.

Root structure

The root system of the mangosteen is fragile, slow-growing and readily disturbed. Transplanting of seedlings has to be carried out carefully, care being taken not to damage to long tap root which has very few laterals. Root hairs appear to be absent on both main and lateral roots.

Bordeaut and Moreuil (1970) have described the development of the root system of mangosteens growing in the Ivory Coast and observed that, in trees 3-8m tall and with a canopy spread of 2-5m, the main portion of the root system developed at a soil depth of only 5-30cm; the longest root did not extend to more than 1m from the base of the trunk.

Leaf Structure

The opposite, simple leaves have short petioles which closely clasp the shoot, the apical pair of leaflets conceal the terminal bud. The leaf blades, which have petioles 1.5-2.0cm long, are ovate, oblong or elliptical and are 15-25cm long x 7-13cm wide; they are shiny, thick and leathery, entire, acuminate at the apex and glabrous. They are olive-green above and

yellow-green beneath with a pale green central nerve which is prominent on both sides; there are also many evenly spaced, parallel, prominent side nerves, at right angles to the main axis (Verheij, 1991).

The mature leaves are believed to survive for several years, with new leaves developing on most of the branches, resulting from new flushes which occur once or twice a year. Young leaves have a pink tinge which changes to light green but this colour lasts for only a very short period and they soon acquire the characteristic dark green colour of mature leaves (Plate 5).

Flower structure

Garcinia mangostana L. is dioecious and differs from many other tropical trees in that the fruits are reproduced by parthenogenesis, that is, they are produced without fertilization. Male trees are reported to carry clusters of 8-9 small flowers at the tips of branches but this type of tree is rare to non-existent and it is likely that these reports resulted from mis-identification of the species; *G. malaccensis* is very similar to *G. mangostana*. Only trees with female flowers are found in cultivation and these produce fruits with apomictic seeds when grown in isolation. Female flowers are solitary, or occasionally in pairs, and develop at the extreme tips of young branches.

The female flowers are 5-6cm in diameter and have four sepals and four petals which are borne on short, thick pedicels. There appear to be different accounts of floral structure in the literature and the exact situation regarding floral structure needs clarifying. The following descriptions are considered to be currently acceptable and are based on those given by IBPGR (1986) and Verheij (1991).

The 4 sepals are large, persistent and biseriate. In the bud, the 2 inner sepals are entirely enclosed by the outer pair, which are 2cm long, and are smaller and bordered with red. The 2 outer sepals, which are 2cm long, are yellowish green, concave and obtuse; the 2 inner sepals are shorter and pink in colour. The 4 petals are broadly ovate, obtuse, thick, fleshy, yellowish green and are either bordered with red or are almost entirely red; they are 2.5cm wide x 3.0cm long. The staminodes, which are numerous, are more or less arranged in groups of 1 to 3 in 1-2 series, forming a ring

Plate 5. Trees showing vegetative flush, with light green young leaves and dark green, glossy mature leaves.

around the base of the ovary. They are free or shortly connate at base, 0.5cm long and bear small and sterile anthers. The ovary is sessile, subglobose and 4- to 8-celled. The prominent, thickened stigma is sessile and bears as many lobes as there are cells in the ovary. The flowers are short-lived; they open in the late afternoon and the petals fall shortly after.

Fruit structure

The normally parthenocarpic fruit is a globular, indehiscent berry, flattened at the base where it is subtended by the persistent fleshy calyx and stigma lobes; the remains of the stigma lobes are evident at the terminal point of the fruit. Fruits are spherical or slightly flattened and are relatively small, ranging from 3.5-8.0cm in diameter. Fruit weights vary from 75-150g, depending on the age of the tree and its geographical location.

The pericarp, rind or skin of the fruit is smooth, 4-8mm thick, tough, purple violet or deep brown-purple externally and purple-violet inside, and contains a yellow, bitter resinous latex. When young fruits are injured, yellow drops of this latex are exuded. The mature, tough skin forms an excellent protection for the soft, edible pulp and facilitates packing and transport (Plate 6).

The skin encloses the edible pulp or aril which consists of 4 to 8 white or ivory-coloured segments, some of which contain a developed or an undeveloped seed, although fruits seldom have more than 2, rarely 3, developed seeds. The pulp normally constitutes 31% of the whole fruit. The segments are generally unequal in size and it is usually the 1 or 2 larger segments which contain the seeds. The aril, which separates easily from the pericarp, is juicy, subacid, exquisitely flavoured, and faintly aromatic. The large, flattened, dark purple or brown seeds are enveloped by weak fibres which extend into the aril.

Seed characteristics

The brown seeds, which are 2.0-2.5cm long, 1.5-2.0cm wide and about 0.7-1.2cm thick, are formed from nucellar tissue in the parthenocarpic fruits (Samson, 1986) and are, in fact, clonally produced since they are apomictic. When cleaned, they appear to be somewhat kidney-shaped and

Plate 6. Developing and mature fruits of mangosteen

bisected; they sometimes resemble two seeds combined in one. A scar which indicates the point of attachment of the aril to the seed is seen on the surface of the seed; this spreads into a network of distinct lines across the seed. There appears to be no clear embryo and no clear evidence of the location of a plumule and radicle, although a close examination indicates the probable existence of an embryonic axis extending throughout the entire length of the seed. The seed has been referred to as a tuberculous hypocotyl. Seed weight is highly variable, ranging from 0.1 to 2.2g, with an average of 1.0-1.6g.

Physiology

Vegetative growth

The mangosteen has an unusually long juvenile phase and plants raised from seed do not normally begin to fruit until 10 to 12 years from field establishment. However, under optimal cultural management, the juvenile period can be reduced to 8 to 10 years. In Thailand, it has been reported that the mangosteen takes only 5 to 6 years to reach its productive phase but this is apparently associated with a prolonged period in the nursery which may extend from 3-5 years; the juvenile phase is presumed to end when the plant has produced 16 pairs of lateral shoots.

In Indonesia, a similar situation exists but, since the soils in Java and Sumatra are volcanic in origin and are extremely fertile, a relatively rapid growth rate could be expected (Sunaryono, 1987). The long juvenile period is probably due to several factors, notably the slow rate of growth of developing seedlings. Unlike the seedlings of most other fruit trees, the mangosteen has a root system which is fragile and lacks root hairs (Hume, 1950).

Growth regulatory substances

Observations made on the growth of mangosteen in northern Australia have shown that growth generally proceeds mainly as a result of intermittent flushes, the frequency of the flushes depending on the age of the plant. Young trees may produce 6 flushes per annum, bearing trees only 1 or 2. Under controlled growing conditions, flushing occurred at

intervals of 40-45 days during the first 18 months of seedling growth (Downton et al., 1990). Between flushes, the terminal bud appears to become dormant (Hume, 1947) and it has been suggested that any treatment which can accelerate the breaking of this bud dormancy may increase the growth rate. Wiebel et al. (1992) found that treatment of the bud with gibberellic acid (GA_3), particularly in 1-3 year old seedlings, was effective; cytokinins were effective only in very young seedlings and auxins were generally ineffective.

Growth rate and CO_2 levels

The mangosteen is adapted as an understorey crop in tropical rainforest conditions and young seedlings exposed to direct sunlight become stunted, with scorching of the leaves and a reduction in flushing efficiency. Two year old plants were observed to grow well under 50% shade (Wiebel et al., 1992). Downton et al. (1990) postulated that high light intensities affected the effectiveness of photosynthesis and the production and movement of assimilates. This was also related to the low number of stomata, which only occur on the lower leaf surface and the limited CO_2 gas exchange capacity of the leaves.

It was found that increasing the level of CO_2 in controlled environments produced an increase in dry weight 77% higher than that of plants grown in ambient CO_2 concentrations. Further studies are intended to provide a solution to the normally poor growth of mangosteen seedlings (Wiebel et al., 1992). Research in Malaysia on the photosynthetic response of mangosteen seedlings to increasing levels of carbon dioxide, also the effects of shading and waterlogging on mangosteen, has also been carried out by Ramlan et al. (1992).

Current research being undertaken by the CSIRO Division of Horticulture, Australia, is aimed at integrating the environmental factors affecting mangosteen growth in order to explore the production physiology. Orchard performance in northern Australia is also being used to evaluate the optimum agronomic practices required to make the crop commercially viable (Wiebel et al., 1992).

Floral development

It has been observed that prolonged dry weather affects the reproductive physiology of mature trees, particularly those grown in mixed orchards or home gardens. An example of this occurred in 1992, in Selangor State, Malaysia, when a dry period of about 14 weeks occurred. Mangosteen trees flowered profusely but mainly on terminal branches rather than also on the less exposed branches. Extensive flower and fruit drop occurred throughout the fruiting season. The fruits which did develop were much smaller in size than usual; they also suffered from physiological disorders and approximately 60% were unfit for consumption.

Ong Hean Tatt (1976) has reviewed the literature available on the effects of drought and the resulting water stress in stimulating flowering in mangosteen and other tropical fruits. It was apparent that water stress, with the probable involvement of inhibitor hormones, is essential to induce floral initiation but that subsequent floral maturation required an adequate water supply combined with good growing conditions. The possibilities of using growth retardants to simulate water stress or to counter stress inhibitors by applying suitable growth promoting chemicals were considered to be feasible as well as a regulation of irrigation levels and frequency.

Floral initiation can be considered to occur when the terminal bud begins to swell. From this stage, about 25 days are required for anthesis, the fruit ripening from 100-120 days later. Flowering, which may occur once or twice a year, usually follows shortly after a vegetative flush (Verheij, 1991).

Genetics

The diploid chromosome number ($2n$) of the mangosteen has been variously recorded as: 56-76, 88-90, 96 and 120-130 but cytological studies by Tixier (1955) indicated a diploid chromosome number of 96; he therefore concluded that the cultivated mangosteen was a polyploid since other *Garcinia* species such as *G. hombroniana* have a diploid number of 48.

Later work by Jong et al. (1973) indicated that the mangosteen is probably a high-level polyploid. Richards (1990b) also concluded that the mangosteen is a polyploid ($2n$ = ?90) and probably tetraploid, and may be the allotetraploid derivative of *G. malaccensis* ($2n$ = ?42) and *G. hombroniana* ($2n$ = 48); the mangosteen is morphologically intermediate between these two diploid species. Lim (1984) and Richards (1990a) have shown that mangosteen is an obligate agamosperm which reproduces by the adventitious budding of proembyos from ovular tissues.

Genetic variation

Although it is believed to have been in cultivation for centuries, there appear to be no distinct varieties of mangosteen in South-east Asia and there are no records of attempts being made to improve the basic species. Although the mangosteen is now mainly known as a cultivated species, there have been occasional reports of sightings of wild forms in Borneo, Malaysia and Kalimantan, Indonesia. There have also been recent reports that some 'varieties' grown in Sabah and Sarawak have been found to be more oval than round; the fruit size also varied and one particular type produced fruits which were twice the normal size. Burkill (1966) also reported that a race of mangosteen, growing in the Sulu Islands, had a much thickened rind and a distintly acid pulp; Almeyda and Martin (1976) also referred to a form growing in Borneo which had 4 segments and 4 seeds.

It is possible that the evolution of mangosteen has ceased, since the species is known to consist of a single genotype which reproduces apomictically by seed; this factor is probably of importance in relation to a limitation of cultivar improvement.

In Malaysia, only female-flowered trees were believed to exist (Purseglove, 1972), but a more recent report (Idris and Rukayah, 1987) has produced evidence of the existence of at least one male mangosteen tree, about 70 years old, growing in the Negeri Sembilan region of Peninsular Malaysia. The tree characteristics were similar to those of the female tree but the male flowers were smaller than female flowers. In addition, the stamens in the male flower were numerous and arranged in a mass; in the female flower, the 18 or so staminodes are arranged in groups

of 1-3 around the base of the ovary. The filaments of male flowers are much shorter than those of the female flowers.

Later studies by Richards (1990b) suggest that this plant could be a hybrid between mangosteen and either *G. malaccensis* or *G. hombroniana.* He concluded that all mangosteens were probably the asexual progeny of a single hybrid female and essentially represent a single seed-reproducing clone. Such genetic variation as does exist is likely to have arisen from somatic mutation, or possibly from occasional back-crossing to hybrids with males from related species. Such mutation or back-crossing could well have occurred in Peninsular Malaysia.

Environment-induced fluctuations

Most descriptions of mangosteen from the Malay Peninsula, Myanmar, the Indonesian Archipelago and the New World indicate that there are no distinct cultivars and it is likely that any differences in the sizes of fruit, seed and taste of pulp can be attributed to environmental factors. Studies by Harjadi et al. (1989), for example, have shown that shade can reduce the size of fruits from trees which are less than 10 years old. The covering of fruiting branches by invasive cover crops such as *Mikania scandens* also reduces the fruit size from mature trees which are aproximately 25 years old. However, in the south of the Philippines, a form of mangosteen called Jolo is cultivated; this bears fruits which are somewhat larger than those of the Malay Peninsula (Horn, 1941).

There are also early reports of forms growing in Java which had a superior flavour and some trees in Burma have been reported to have a late-ripening habit (Brown, 1936). Oberti (1968) observed that, in Nicaragua, there were two types of mangosteen which differed in fruit and leaf sizes. More recently, a relatively new type of mangosteen, which has a better taste compared with the existing cultivated species, has been found growing wild in the Malaysian forests.

Despite the apparent lack of genetic variation in this species, certain fruit characteristics such as thickness of pericarp and pulp have been observed to vary between individual trees. This would appear to suggest that a potential for variation may exist in the mangosteen and it is suggested

that this variation could be exploited to further improve existing cultivated forms. For example, fruits from young trees of 8-12 years of age, grown in mixed orchards, are smaller than those from trees which are 15-25 years old.

Genetic erosion

Severe genetic erosion of mangosteen has apparently occurred in South-east Asia, according to Sastrapradja (1975) and he considered that there are no truly wild populations of mangosteen, of either male or female trees. Other *Garcinia* species, which may be useful for their fruits, use as rootstocks, or in future breeding programmes are likely to be under considerable threat as their habitats continue to be destroyed. A significant gene pool, awaiting investigation, is probably available in the forests of Malaysia and Indonesia.

Some germplasm collections of mangosteen and related *Garcinia* species exist in Thailand, Indonesia, the Philippines, Florida, USA and, possibly, in South China (IBPGR, 1986).

CHAPTER 4. ECOLOGY

The mangosteen is native to the Malay Peninsula and its cultivation outside this area is largely restricted by its particular climatic and edaphic requirements. In general, the most suitable climate for mangosteen is a warm, humid one and areas with well distributed rainfall through the year, but with a short dry season, are preferable. The potential range of the mangosteen extends to 18° latitude in warm, frost-free areas and trees may be grown at elevations up to 1,000m although the growth rate is higher in lowland areas (Verheij, 1991).

Soils

The chief soil requirements appear to be deep, permeable soils with high moisture and organic matter contents; these are possibly related to the relatively weak root system of both seedlings and mature trees. The nutrient requirements of mangosteen trees are also relatively high. Areas with these edaphic characteristics include the west coastal belt of Peninsular Malaysia, the upper parts of southern and eastern Thailand and the flat alluvial plains in Borneo, Kalimantan, Sumatra and Java. In the Philippines, bearing trees may be found in the Manila, Pampanga and Negros Oriental areas. The climatic conditions in these regions favour very rapid decomposition of organic mulches below the trees, resulting in high organic matter accumulation.

Mangosteens grown in Sri Lanka and Panama are reported to thrive in very moist soils, with a high water table, providing that the water is not stagnant, ensuring a certain degree of aeration. It has also been suggested that mangosteens will often thrive when planted alongside river banks, canals, ponds or lakes (Almeyda and Martin, 1976). In India, the most productive trees grow on coarse clay soils containing some sand and silt and which have good water-retaining properties.

Sandy, alluvial soils are unsuitable and soils low in humus generally contribute to low yields; good drainage is essential (Morton, 1987). In general, deep clay loams or silt loams with good drainage appear to be most suitable for satisfactory growth. Many other soil types have been found suitable for growing mangosteen but trees have been observed to

grow slowly and die prematurely on poor and alkaline soils (IBPGR, 1986).

The optimum soil pH level appears to be within the range 5.5-7.0 but no detailed investigations of the actual requirements appear to have been carried out. The tolerance of mangosteen to saline soil conditions is considered to be low although no specific studies in this area are available.

Rainfall and Water Requirement

Rainfall appears to have a major influence on the pattern of geographical distribution and the seasonality of bearing of the mangosteen in parts of South-east Asia. In Malaysia, most of the areas cultivated with mangosteen have been described by Nieuwolt et al. (1982) as locations which have short but fairly regular dry seasons, such as the central and south-eastern regions. In areas where there is a distinct and prolonged dry period, as in the eastern and northern parts of Malaysia, the mangosteen does not appear to grow satisfactorily. Eastern Thailand and parts of southern Thailand also have rainfall conditions which favour mangosteen production.

In areas where the rainfall is inadequate, however, the use of irrigation results in satisfactory crop growth. These comments were confirmed by Hume and Cobin (1946) who stated that mangosteen requires a well distributed annual rainfall, exceeding 1270mm. Terra (1949), in studies carried out in Java, Indonesia, concluded that mangosteen grew well in areas in which more than 100mm of rain fell in each month although trees were not harmed when the rainfall level fell to 60mm or below during one or two months. Observations made in the Hainan Province of China have indicated that serious drought over 4-6 months causes drying of leaf tips and margins, accompanied by a delay in flowering until the next rainy season and a reduction in fruit size and quality (Chau Kay-Ming, 1990).

It is therefore apparent that the mangosteen thrives well in areas which are neither too dry nor too wet. Under dry conditions, mangosteens are subject to establishment problems. Similarly, if the growing environment is too wet, trees will probably fail to flower adequately, adversely affecting

crop yield. There are indications that mangosteen trees probably require a certain degree of water stress for flower induction.

Hume (1950) considered that the water requirements of mangosteen depend directly on the status of the water table as well as on the type of soil; it is generally considered that the water table should be not more than 2m below the soil surface.

Temperature and Humidity

Temperatures below 5°C and above 38°C can be lethal and temperatures lower than 20°C may retard growth (Hume, 1950; Krishnamurthi and Rao, 1962). Furthermore, an annual rainfall of above 1270mm and some shelter or shade is necessary. The ideal temperature would appear to be in the range 25°C to 35°C, with a relative humidity of at least 80% (Bourdeaut and Moreuil, 1970)

Day length

Hackett and Carolane (1982) stated that mangosteen trees will flower in both long and short daylengths, although the most prolific crops usually follow long day flowering.

Shade Requirements

In its natural habitat, the mangosteen grows as an understorey plant in the forest and, under mixed holding conditions, equivalent shading is often provided by other trees. In Malaysia, the mangosteen is extensively grown in association with durian and rambutan, particularly in the States of Johor, Negeri Sembilan, Pahang and Perak.

The effect of shade on the performance of trees and the quality of fruits produced has not yet been fully studied. There are indications, however, that mangosteens can tolerate both open and shaded conditions since they are grown under both these conditions in the major mangosteen producing areas. Studies by Harjadi et al. (1989) in Java, Indonesia, have shown that shade from nearby trees tends to decrease plant height, reduce canopy density and delay fruiting of 10 year old mangosteen trees.

Hume (1950) considered that shading was beneficial to cultivated trees, particularly during the first 4 to 5 years of growth and it appears that shade during this period is required to protect the delicate growing points of the young mangosteen trees from the scorching effects of the sun. Once such growing points are damaged, growth can be severely retarded. This effect is linked to the fact that the mangosteen root system is both weak and poorly developed.

Unpublished field studies, carried out by MARDI in Malaysia, showed that young seedling plants, obtained from various sources, when planted in the open did not perform well; some plants appeared stunted and the majority showed irregular leaf flushing. However, young seedling plants were found to respond very well to shaded conditions. Under both irrigation and shade, plants were observed to grow more rapidly since the internodes elongated regularly although the plant appeared to be somewhat etiolated. Supports are required for such plants. Intercropping trials, carried out in Perak in Central Malaysia, also showed that mangosteens grown under coconut shade produced fruits 4-5 years after planting when irrigation, fertilizers and adequate pest and disease control measures were regularly provided.

In northern Australia, an innovative grower has been reported to provide shade for young mangosteens by intercropping with pigeon pea (*Cajanus cajan*) and banana (*Musa* spp.). All the three crops were provided with extra irrigation and fertilizers and early returns were obtained from the shaded crops.

As a result of its slow growth rate, the mangosteen is regarded as being a difficult plant to establish. For this reason, Malaysian and Australian studies on overcoming the problem of establishment have been emphasised in recent years; these have included work on shade requirement levels and the use of growth regulators to enhance vegetative growth. The main objective of these studies has been to promote tree growth rate during the establishment period and also to reduce the extended juvenile phase of the crop (Sharif Achmad et al., 1973; Sunaryono, 1987; Wiebel et al., 1991).

Wind

Strong winds are likely to cause serious injury to leaves and branches and windbreaks are recommended in exposed areas (Chapter 8).

Studies on the ecophysiological requirements of mangosteen would therefore appear to require further emphasis so that it will become possible to formulate improved cultivation and management systems.

SECTION II. MANGOSTEEN CULTIVATION

Reviews of Cultural Techniques

Reviews of the various techniques used, in different geographical areas, in the cultivation of mangosteen have been given by various authors, including: Abidin (1990); Almeyda and Martin (1976); Bordeaut and Moreuil (1970); Chau Kay-Ming (1990); Cox (1976); Gaillard (1978); Hackett and Carolane (1982); IBPGR (1986); Luna (1984); Morton (1987); Ochse et al.(1961); Verheij (1991); and Wiebel et al. (1992). Buisson (1986) has also reviewed aspects of physiological development and propagation.

CHAPTER 5. PROPAGATION.

Propagation by seed

The importance of seed size and the effects of the composition of the growth medium on the early growth and development of the mangosteen have been investigated by Almeyda and Martin (1976) and Zabedah and Rukayah (1988).

In mangosteen, the embryo initially develops in the inner integument and only one is normally produced; although polyembryony, the production of several identical seedlings, may occur in about 10% of seedlings (Krishnamurthi and Rao, 1965). Pollination and fertilization are not required for seed development since the fruits are parthenocarpic (Sedgley and Griffin, 1989). Mangosteen seeds are generally regarded as being recalcitrant (Chin, 1978; Chin and Roberts, 1980) and rapidly lose their viability if the thin membrane surrounding the seed is damaged.

Traditionally, the mangosteen has been propagated by seeds and, since they are formed from nucellar tissues (Corner, 1952), they produce apomictic seedlings which, when fully grown, are identical to the parent tree (Horn, 1940). If seeds are removed from the fruit and are kept at ambient temperatures for several days prior to planting, germination can be drastically reduced. However, seed vigour can be maintained for up to 3 to 4 weeks if the seeds remain within the fruit; they may also survive for

almost this period if stored in moistened charcoal or peat moss in sealed containers kept at ambient temperatures.

Seed selection

Seeds are preferably selected from fruits produced as a main crop, preference being given to large-sized and also early ripening fruits, to avoid selecting for an inherited late-fruiting characteristic. The weight of seeds is highly variable, ranging from 0.2 to 2.2g, with an average of 1.0 to 1.6g. This variation in weight results in significant differences occurring, not only in germination but also in subsequent growth and survival, since there appears to be a positive correlation between seed weight and plant size after one year of growth (Hume and Cobin, 1946).

This is due to the greater food reserves possessed by larger seeds, enabling the seedling to survive adverse conditions during the extended root development phase; this is also related to the ability of more vigorously growing roots, although with a limited root hair development, to have increased access to water and nutrients. Hume and Cobin (1946) reported that high germination and survival rates were obtained from seeds weighing more than 1.3g and it is now generally recommended that seedlings be raised from seeds weighing more than 1g.

Seed sowing and germination

Seeds are prepared for sowing by rubbing the mixture of pulp and seed in fine sand. They should be soaked for about 24 hours before sowing; unsoaked seeds may have a very low germination percentage. Treatment with growth regulators to enhance germination has generally proved ineffective but *in vitro* germination of selected seeds sterilized with 19% chlorox has been observed to give a satisfactory germination percentage of about 76% of normal seedlings. Since seed vigour is rapidly lost when the moisture content falls below 20%, seeds must be sown immediately after the removal of the pulp..

Seeds should be sown in a medium which is high in organic matter but which is also well drained. This can be achieved by mixing topsoil, preferably of a sandy clay-loam type to which the roots will adhere on

transplanting, with fine sand, coir dust, dry palm oil mill effluent, peat or other suitable organic materials. Horn (1941) recommended the use of sphagnum moss as a medium. In Malaysia, a growing medium containing soil, organic matter and sand in a 3:2:1 ratio was found to be the most suitable mixture (Zabedah and Rukayah, 1988).

Wiebel et al. (1992) investigated growing media and their effects on the growth of seedlings grown in northern Australia and found that the main factors influencing satisfactory growth were probably good aeration and pH level. A very porous medium, supplied with additional nutrients and iron chelates, was found to be most suitable; a pH level of 6.2 was considered appropriate. Seeds are normally sown at a depth of about 1cm and should be well shaded and watered.

The average period required for seed germination can vary considerably, from 10-50 days, depending on seed age and the medium used for sowing; seeds from the same tree have also been found to vary considerably in germinating behaviour in different years. The mode of root and shoot development of the mangosteen seed is unique. One end of the germinating seed usually produces a shoot which grows upwards and the opposite end gives rise to a root. It is not always easy to determine the exact location of these two early growth sources on the seed but the position of the seed in the sowing medium does not appear to affect germination.

According to Hume and Cobin (1946) and Almeyda and Martin (1976) normally one, but occasionally two shoots emerge from the seed and two distinct root systems are developed, the distal one degenerates after a short period. After 6-8 weeks, the vertical shoot produces leaves and the root develops directly below the shoot. When two or, rarely, three polyembryonic seedlings arise from a single seed these are almost always smaller and weaker than a single seedling and should normally be discarded.

Plate 7. Seedlings grown under shade

Transplanting

When seeds are sown in beds, the seedlings should normally be transplanted at the two-leaf stage, care being taken to preserve an intact ball of soil around the roots. Care in transplanting is particularly important, whether the seedlings are being transferred from seedling beds or containers, since any damage to the main taproot will seriously reduce the potential for survival of the seedlings.

Several recommendations for reducing root injury on transplanting have been made by Almeyda and Martin (1976). The period to reach the two-leaf stage will vary and will depend on the seed size, seed vigour, type of medium and growth conditions. The survival rate of transplants has been observed to decline with increasing age of the seedlings (Horn, 1940). Slow seedling growth is generally attributed to a weak root system, characterized by the absence of root hairs and poor lateral root development.

Under favourable conditions, with regular watering and adequate shading, plants may reach a height of 30-35cm and develop a leaf area of more than 200cm^2 after one year; the rate of growth is considered to be the slowest of almost all tropical fruit seedlings which have an extended juvenile period.

In some areas, seeds are sown directly into 18 x 10cm polyethylene bags and are later transferred to 30 x 19cm bags, normally after the second pair of leaves has developed, which may be three or four months later (Bordeaut and Moreuil, 1970). Seedlings can be transplanted into the orchard after 1-2 years, when approximately 45-60cm high.

Due to the weakly-developed root system, however, it is recommended that transplanting be carried out when seedlings are no more than 60cm high since the taproot may be extensively developed by that time. The use of anti-transpirants, to reduce stomatal water loss, has also been suggested. The selection of vigorous seedlings in the early growth stages ensures the survival of vigorously growing trees (Almeyda and Martin, 1976).

Nursery techniques

As the demand for planting material increases, improved nursery techniques have been introduced, particularly in southern and eastern Thailand. One such technique is to plant one-year old seedlings in a moist, deep, sandy clay loam soil in large polybags or bamboo baskets in which they remain until they are about one metre high. When the seedlings have been hardened off, they are ready for transplanting to the main orchard. When they have become established, appropriate fertilizer and irrigation regimes, as well as shading, are provided. Under good management, trees may come into production within four to five years from planting.

There are, however, several limitations to propagating mangosteen by seed, some of which have already been discussed. These are (a) the delicate root system of young seedlings, (b) the extremely slow growth of the resulting plants, and (c) the long period required before the seedling trees begin to produce fruits. Several attempts have therefore been made to propagate the mangosteen vegetatively but these attempts have frequently given poor results although some techniques may have potential use in the future.

Rootstocks

Rootstock selection

Since mangosteen seedlings take from 10-12 years to come into bearing, some attention has been directed towards rootstock selection and propagation techniques, with the objective of promoting earlier bearing. Initial attempts by MARDI in Malaysia to propagate mangosteens by root cuttings and by grafting selected scions onto *Garcinia atroviridis* were unproductive, although this rootstock had been successfully used in southern Thailand and was found to reduce the juvenile, non-bearing phase from 12 to about 6 years. A similar failure to bud graft mangosteen onto other types of rootstock had been reported earlier by Krishnamurthi and Rao (1965) and Ochse (1964).

Popenoe (1974) suggested that possible root stocks for mangosteen included *G. tinctoria* and *G. morella* from Malaysia and *G. livingstonei*

from East Africa. *G. morella* has a relatively short tap root, whereas the longer tap root of *G. tinctoria* is liable to damage on transplanting. *G. xanthochymus*, due to its relatively vigorous root system, would also appear to be a suitable rootstock (IFAC, 1967); *G. spicata* was also considered to be a potentially useful species. It has also been suggested that *G. speciosa*, which appears to have some drought resistance and is graft-compatible with the mangosteen, may possibly be useful as a rootstock.

Another species which is closely related to mangosteen and which may be suitable as a rootstock is *G. hombroniana*, which is also found in the Malaysian area (Halijah Ibrahim, 1988); the seeds germinate readily and plants flower in 5-7 years from seed. *G. cochinchinensis* has also been suggested as a suitable rootstock (Alexander et al., 1982), as has also *G. cambogia*, used in India as both a fruit and a source of dye. Gonzalez and Anoos (1951), in their studies on mangosteen grafting, found that *G. kydia, G. venulosa* and *G. morella* were all compatible with mangosteen. *G. malaccensis* has also been suggested as a potentially useful rootstock (Richards, 1990b). All of the above-mentioned species have a more vigorous root system than *G. mangostana*, they are also generally hardier and grow more rapidly. It is still, however, common practice to use *G. mangostana* as a rootstock, when no alternative species is available.

Rootstock production

Various forms of layering and grafting have been used, with varying levels of success, but since these all depend on the production of vigorous rootstocks, only large seeds are selected for rootstock production. The seeds are sown in black, perforated polybags which measure about 25cm x 35cm when laid flat, in a medium consisting of soil, organic matter and sand in a 3:2:1 ratio (Chang and Azizan, 1984; Zabedah and Rukayah, 1988). The seedlings grow very slowly and may remain for more than 2 years in the polybags before they are suitable for grafting. They require shading, regular fertilizers, including liquid formulations, and irrigation; a hardening-off process is generally required before the seedlings are used as rootstocks.

Plate 8. Saddle grafted plants

Plants used as rootstocks must be in an active stage of growth and seedlings ranging from one to three years of age are normally used. It has been generally accepted that older rootstocks give a better success rate than younger rootstocks but Gonzalez and Anoos (1951) reported that young rootstocks, about 2 months old, made a more rapid union with scions than older rootstocks. The later performance of these grafts was not reported.

Budding

Attempts to use shield budding on various rootstocks, including *G. mangostana*, have been generally unsuccessful, due mainly to the exudation of the yellow resin characteristic of this genus (Almeyda and Martin, 1976). Patch budding, in which the cuts are made 6 days before budding, has been suggested as an alternative, but no results appear to have been published (Fielden and Garner, 1936). Early work in the Philippines by Wester (1920) indicated that shield budding on to *G. dulcis*,

using large-sized buds, could be successful.

Air Layering

Very limited success has been achieved in producing clonal material by air layering or marcotting and experiments were reported to be generally unsuccessful in India (Krishanamurthi and Rao, 1965), in the Philippines (Gonzales and Anoos, 1951) and in the Ivory Coast (Bordeaut and Moreuil, 1970) although limited success was reported by Macmillan (1935) in Sri Lanka. The main problem encountered was poor root formation. In Thailand, some success was obtained with marcotting by incorporating plant growth regulators in the media (Anon, 1961).

Cuttings

In The Ivory Coast mangosteen cuttings appeared to root well under the high humidity conditions created by misting installations and this appears to be the most promising method of producing mangosteen asexually, at the present time, although results in other areas have been disappointing (Bordeaut and Moreuil, 1970). Wiebel et al. (1992) have indicated that cuttings taken from germinating seedlings root well under mist propagation conditions but that cuttings from more mature trees rarely root satisfactorily.

Grafting

Propagation by grafting, using mangosteen seedlings as rootstocks, has been found to be possible but difficult. Local nurserymen in various areas use various forms of grafting as a means of increasing the value of nursery plants but since there is, as yet, no rapid and inexpensive method of propagating mangosteen vegetatively, the use of seedlings as a means of propagation remains the most widely used method of multiplication.

Inarching

Earlier work on inarching carried out in Puerto Rico by Oliver (1911) resulted in success using about 20 different types of rootstock although

only *G. livingstonei, G. morella* and *G. tinctoria* were considered promising. Several other workers reported success with other types of rootstock and various grafting techniques (Thayer, 1961; Gonzales and Anoos, 1951 and Stephens, 1935).

Saddle grafting

Recent studies have shown that the type of saddle grafting developed for cocoa (Krishnan et al., 1980) is also suitable for mangosteen propagation, using five-month old seedling rootstocks, and an 85% success rate is commonly obtained.

A well-maintained five-month old seedling, 10-15cm high, is selected as a rootstock. The seedling is then pruned back to a height of 4-6cm and any remaining leaves are removed. Two cuts, each about 3-4cm long, are made on opposite sides of the stem to form a tapering wedge (Figure 2(b)).

A healthy terminal mangosteen shoot from a mature tree is selected as the scion. The shoot selected should be about 6-8cm long and should have at least two leaves. The leaves on the scion are reduced to two and these are reduced to about half their length to reduce transpiration loss (Figure 2(a)).

The scion is then slit vertically upwards from the centre of the base, for a distance of about 3cm (Figure 2(a)). The scion is then placed on top of the previously prepared rootstock, ensuring that at least one side of the cambium of the bisected stem is aligned firmly with the cambium of the rootstock (Figure 2(c)). The wound is then covered with plastic tape or wax to exclude air and water (Figure 2(d)).

The grafted plant is then covered with a plastic bag which helps to maintain a high level of humidity around the plant (Figure 2(e)). Prior to covering, the plant is adequately watered; careful application is required to avoid wetting the grafted areas. The plastic bag is removed when the scion begins to grow; this normally occurs about one month after grafting (Chong and Chai, 1986). Figure 2 shows the various stages involved in the saddle-grafting technique and Plate 8 illustrates plants which have been successfully propagated using this technique.

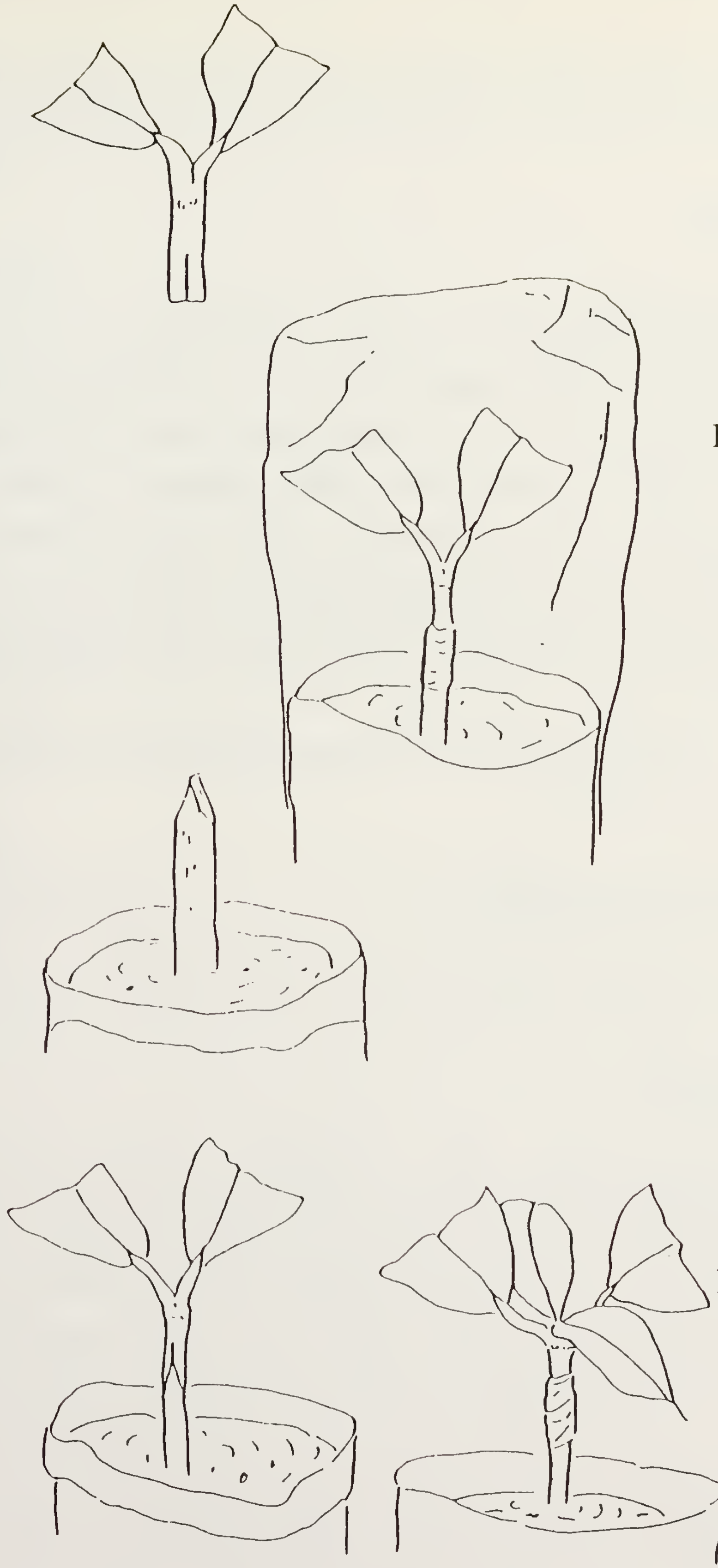


Figure 2(a)

Figure 2(e)

Figure 2(b)

Figure 2(c)

Figure 2(d)

Figure 2. Procedures used in the saddle-grafting technique

It has been observed that saddle-grafted plants may fruit as early as six years of age.

Cleft grafting

In the cleft grafting method, a healthy terminal shoot bearing two leaves and about 5cm in length is used as the scion. The base of the scion is cut into a wedge or V-shape and inserted into a slit made on the seedling rootstock which has been previously been pruned back to about 10cm high. The grafted portion is then firmly wrapped with plastic, ensuring that the scion is in the correct position. The grafted plants are maintained in cool and humid conditions under at least 75% shade. Scion growth normally occurs about 4 weeks after grafting. Table 5 gives a comparison of the success rate of 2 and 4 year old rootstocks when cleft grafted.

Table 5. Average percentage of success of cleft-grafted mangosteen on 2 and 4 year old rootstocks

Rootstock age (years)	Percentage success
2	62
4	80

Wedge grafting

Wedge grafting, using 2 year old seedlings 30-35cm high, has been reported to have given successful results (Abidin, 1990). The terminal shoot of the stock is removed and the cut surface is prepared by making a V-shaped incision. The scions should be of the same diameter as the stock, to ensure cambial union. They are cut into a wedge shape at the lower end and inserted into the incision made in the stock plant. Scions should have 2 leaves, which are reduced by half to reduce transpiration. The graft is bound with plastic tape and the grafted plants are kept in cool, moist conditions with about 25% light penetration. Scions normally produce shoots in 1-2 months after grafting and results have varied from 62-80%.

In Sri Lanka, mangosteen seedlings of 2-2.5 and 3-4 years old were used to assess their suitability as rootstocks. When the 2-2.5 year old seedlings

were wedge-grafted, the success rate was 90%. When the 3-4 year old rootstocks were grafted, the success rate fell to 34% (Dassanayake and Perera, 1988).

Approach grafting

Very limited information has been published on approach grafting but it has been reported to be successful in Florida. A seed of *G. tinctoria* is sown in a container in which a mangosteen seedling is growing, about 3cm from the seedling. When the seedling of *G. tinctoria* is about 3mm in diameter it is grafted on the mangosteen seedling about 10cm above the soil level, using the traditional approach grafting technique of removing a slice of stem tissue about 5-6cm long from both stock and scion; these are then bound together with plastic tape. When the union has been successful, the *G. tinctoria* stock is beheaded, leaving the grafted mangosteen with 2 root systems to support it (Campbell, 1967).

Tissue culture

Since vegetative propagation methods used with mangosteen have shown variable results, several workers have investigated the use of tissue culture, with varying degrees of success (Almeyda and Martin, 1976).
Goh et al. (1988) used explants from asceptically germinated seedlings in their *in vitro* studies on the micropropagation of mangosteen. Proliferating shoots were obtained from cotyledon segments cultured on modified Murashige and Skoog (1962) medium with 6-benzylaminopurine. Juvenile leaf segments produced adventitious buds on Woody Plant Medium (Lloyd and McCown, 1981). Multiple axillary and adventitious buds were formed from shoot tips and nodal and internodal explants but root segments produced few buds. Shoots were rooted by indole-butyric acid treatment and were readily established in a vermiculite:sand (1:1) mixture.

Goh et al. (1990) further showed that benzylaminopurine (BAP) at $5mgl^{-1}$ produced optimum shootbud development from seedling explants, but higher concentrations caused clustered and stunted shoot buds. When leaves from mature trees which had turned from red to green were used, the frequency of shoot bud formation decreased. The number of vegetative buds formed was found to be higher in red leaves from

seedlings, compared with young red leaves taken from mature trees. Plantlets from seedling explants were successfully acclimatized and established in soil.

An interesting feature of this research was that, during the growth of shoots *in vitro*, there was enhanced axillary bud formation at the nodes. It appears, therefore, that micropropagation techniques may prove extremely useful in the future in the production of mangosteen planting material.

CHAPTER 6. ORCHARD ESTABLISHMENT, TRAINING AND PRUNING

Many of the existing mangosteen orchards in South-east Asia consist of old and neglected trees. Chan et al. (1982) reported, in 1980,that over 60 percent of the existing trees were over 25 years old. At this time, it was also estimated that the rate of replanting was probably less than five percent. Although accurate current data are not available, it appears likely that, in response to increasing demands for mangosteen fruits, particularly for export, the rate of replanting and the establishment of new orchards is significantly increasing.

There is therefore an obvious need to improve establishment, training and pruning techniques in order to increase the general vigour and productivity of both newly established and mature trees.

Land Preparation and Planting

Site preparation

When only a few mangosteen trees are to be planted, as in home garden planting, the holes which are prepared are normally only large enough to accommodate the ball of soil which surrounds the root system of the seedling or grafted plant. Where a mangosteen orchard is to be established, however, the land preparation techniques used are similar to those employed for other tropical fruit crops, some of which require shade during the early establishment period. Depending on the history of the site, the soil type and slope, land preparation can consist of deep ploughing, possibly repeated, followed by rotavating or harrowing until the desired soil tilth has been achieved.

Where large-scale plantings of trees are to be established on land which has recently been under forest and where the terrain is either gently sloping or undulating, more sophisticated methods can be used. Existing trees should be felled by the use of machines such as bulldozers, stacked for drying for about two months and then burned. A second stacking and reburning are usually required. After the land has been cleared, the soil is ploughed and pre-emergence herbicides are applied to prevent the

regeneration of weeds. A leguminous cover crop mixture, consisting of species of *Calopogonium*, *Centrosema* and *Pueraria*, mixed with a phosphatic fertilizer, is then sown. A good ground cover can be expected to be established within six months. The planting holes can be prepared using a mechanical digger.

<u>Tree spacing</u>

Depending on the soil and climatic conditions existing in the planting area, trees are spaced at intervals of 8-10 x 8-10m, on a square planting but, in marginal and relatively infertile soils, the spacing may be increased to 12 x 12m (Krishnamurthi and Rao, 1962). In the Ivory Coast, a spacing of 10 x 10m is recommended (Bordeaut and Moreuil, 1970) and, in southern India, a spacing of 9-11m is used. In Puerto Rico, Almeyda and Martin (1976) recommended an initial planting distance of 6 x 6m, at a density of 280 trees/ha, allowing for the possibility of later thinning.

Where mangosteen is to be planted as an intercrop with coconut, as in some parts of the Philippines and Malaysia, the seedlings should be established at the centre of the square formed by 4 coconut trees, the coconut palms providing early shade for the young mangosteen plants. Where there is no existing shade, shade plants such as papaya and banana can be established prior to planting the mangosteen and, once these provide sufficient shade, the seedlings can be planted in between these crops (Plate 9(a)).

Preparation for planting

Stakes are inserted at the planting intervals determined by the climate and location of the orchard and holes are then dug at the positions occupied by the stakes. In Thailand, in areas where the soil is fertile, trees are planted in holes measuring 50 x 50 x 50cm deep. For infertile soils, a hole size of 100 x 100cm wide and 100cm deep is usually used. The excavated soil is left to dry for 15-20 days, the holes are then filled with a mixture of compost, well decayed manure and topsoil. Phosphatic fertilizer, applied as rock phosphate, at a rate of 500g/hole, is often mixed in with this planting medium and, in soils which are slightly acid, limestone may also be added.

Transplanting

Seedlings should always be transplanted at the beginning of the rainy season, to ensure rapid establishment of the root system. At planting, the long and delicate tap root of seedlings can be easily damaged, with little prospect of recovery. Whatever method of transplanting is adopted, it is imperative to prevent any damage to the tap root and to encourage the development of new root growth. Seedlings should always be planted at the same depth as they were growing in the nursery bed or container.

Many different methods of transplanting mangosteen have been adopted in various countries. In Honduras and Panama, for example, the seeds are germinated in small pots and, when the seedlings have only two leaves, they are transplanted to shaded seed beds. The plants are transplanted to permanent sites when they are about half a metre high. The main disadvantage of this method is that the plant is transplanted twice. In Burma, it is recommended that seeds are sown in a container 0.3 to 0.4m deep. The seedlings are transplanted to their permanent sites when they are approximately 0.6m high (Almeyda and Martin, 1976).

Before planting, the seedlings are thoroughly watered; they are then transported to the planting site and the polybag is removed from around the roots, using a sharp knife and with minimum disturbance of the soil around the root ball. The seedling is carefully placed in the planting hole and the roots are covered with a mixture of topsoil and well decayed compost. The soil should be gently firmed around the roots, to reduce the possibility of leaving air pockets which could adversly affect the sensitive root system.

In the Ivory Coast, 80-100kg of well-decayed manure or compost is added to each planting hole (Bordeaut and Moreuil, 1970) and the addition of 500g of an NPK fertilizer, mixed with the soil as the hole is filled has also been recommended (Almeyda and Martin, 1976). The previously excavated subsoil should not be used, unless this is essential. An organic mulch should be applied around the base of the plants which should also be well watered.

Plate 9(a). Mangosteen seedlings to be planted between shade trees

Plate 9(b). Young mangosteen trees without shade

Under ideal conditions, growth will be quite rapid, leading to the emergence of side shoots. Since a pair of side shoots develops from almost every node, the symmetrical branch architecture of young trees is quite noticeable. As each of these laterals produce further branches, the canopy becomes quite dense.

Shading

Shading should be provided for at least the first six months after planting. Palm fronds are frequently used as shade; they are very suitable for the purpose since the leaves will gradually dry out, allowing the seedlings to become hardened. It has already been mentioned that a temporary shade crop, which may also supply a cash income to the grower, can be grown as an interrow crop. Crops such as banana and papaya can be established about six months before the mangosteen seedlings are planted. However, these shade crops should be removed two to three years later, before they begin to compete with the mangosteen seedlings.

If a companion crop such as the jackfruit is interplanted with the mangosteen, the rapid growth of the jackfruit may affect the growth of the mangosteen. This situation can occur if the companion crop is allowed to grow for too long. Young mangosteen seedlings which are planted in open land, without shade, generally show a slow rate of growth and an uneven sequence of flushing of the young leaves and, in these conditions, it would be necessary to erect shading over the freshly-planted seedlings and retain this for from 2-3 years. Alternatively, over-shading can cause the plants to grow taller more quickly than normal and support is sometimes required to keep the plants in an upright position.

In Puerto Rico, it has been observed that, after an initial period of shading, trees will grow well and come into bearing early if the shading is subsequently removed (Almeyda and Martin, 1976).

Training and pruning

The general health of mangosteen trees, which is also related to their productivity, can be estimated from the size of the canopy or canopy spread.

Mangosteen trees grow into a well-formed, pyramidal shape and normally require no training during the formative years. However, preventive pruning to remove weak and dead branches and corrective pruning to remove upright-growing branches and smaller inner branches should be carried out regularly. Heading back the tree to a height of 8-10m may be desirable, to reduce plant height to a convenient level for harvesting and promote greater development of lateral branches. A tree growing under favourable conditions may have produced 16 tiers of branches from the main stem by the time of the first harvest which may be 10-12 years from planting.

The removal of weak, under-sized, dead or diseased branches from within the framework of old trees normally results in the promotion of flowering and fruiting. This is particularly true of old trees which have been unproductive for several years. Branches which are in contact with the soil should also be removed. Trees with dense foliage usually produce fruits only at the tips of branches and, consequently, much of their fruiting potential may be lost. A judicious pruning, increasing light penetration into the tree canopy, is therefore a desirable practice. Severe pruning of mangosteen may, however, considerably reduce the level of production (Almeyda and Martin, 1976).

Pruning is preferably carried out when the trees are not bearing flowers, fruits or new leaves and the best time to prune is normally soon after harvesting has been completed.

CHAPTER 7. FERTILIZER USE AND IRRIGATION TECHNIQUES

Fertilizer use

Many mature mangosteen trees form a part of the old *dusun* system in Malaysia, Java and the Philippines and they are therefore rarely given any fertilizer, with the possible exception of occasional applications of organic manure.

Tree response to fertilizers

Specific information on the effects of fertilizers on the mangosteen is generally lacking and many of the existing recommendations are based on empirical trials and traditional practices. It has been suggested, for example, that nitrogenous fertilizers are beneficial in promoting vegetative growth but it is also considered that flowering is also accelerated by applications of nitrogen, particularly when it is applied in the form of nitrates. It is, however, generally accepted that the mangosteen responds well to fertilizer application, including the use of liquid fertilizers and organic manures which are generally applied as a mulch.

Very limited information appears to be available on the response of mangosteen to micro-nutrients although the occurrence of magnesium deficiency in mangosteen leaves was confirmed by Marchal (1972). Chlorotic leaves were found to contain 0.105% of Mg, compared with 0.150% in leaves from healthy trees. A 'little leaf' condition was shown to be due to an imbalance between iron and zinc.

Types of fertilizer

Mixtures of fertilizer are generally recommended, mainly based on nitrogen, phosphorus and potassium (NPK). The constitution of these mixtures has been variously recommended to be 15:15:15, 10:10:9, 10:10:14, and 9:24:24 although this latter mixture is mainly applied to trees prior to the fruit ripening stage. The use of liquid forms of nitrogen, such as urea, is sometimes referred to indirectly as a foliar feed but no specific recommendations appear to have been made.

Fertilizer Applications

Pre-and post-planting

It has already been mentioned that planting holes should receive a dressing of fertilizer, in addition to the incorporation of organic material. Traditionally this dressing consists of superphosphate and, if soils are slightly acid, limestone. The quantities applied are usually in the range of 100-150g of phosphate and 200-300g of limestone; 500g of rock phosphate is sometimes used instead of superphosphate. An NPK fertilizer (10:10:10), at a rate of 200g/hole, could also be substituted for the superphosphate.

Once the plants have become established, monthly applications of sulphate of ammonia, at a rate of 50-100g per tree, will encourage rapid vegetative growth. These applications should be continued for six months after planting.

Routine fertilizer applications

The rate of fertilizer application should be gradually increased as vegetative growth becomes more vigorous. Up to the first harvest, which may be in the 8th year from planting, the practice in Thailand is to apply gradually increasing levels of an NPK (10:10:9) mixture, as shown in Table 6.

Table 6. Annual rates of fertilizer applications, Thailand

Age of tree (Years)	Fertilizer applied (kg)
1-2	0.25
2-4	0.50
4-6	1.00
6-8	2.00
8-10	4.00
10+	7.00

The dressings are given in two equal applications, frequently at the beginning and the end of the rainy season.

Husin and Chinta (1989) have made recommendations for the fertilizer treatments required by crops grown on low fertility soils such as the highly weathered Ultisols and Oxisols in Malaysia. These included regular dressings of young trees with an NPK 15:15:15 formulation at a rate of 0.5-1.0kg/tree, together with regular dressings of organic manures. The rate should be increased as trees become older, mature trees receiving 2.5kg/tree/annum of an NPKMg mixture of 12:12:17:2.

Various recommendations have been given for stimulating the flowering and fruiting, and particularly the fruit ripening, of mature trees. These include increasing the nitrate and potassium content of the fertilizer after the 8th year to promote fruiting, also the inclusion of micro-nutrients. The period immediately after harvest is also considered, in some areas, to be important for fertilizer application as a means of stimulating new vegetative growth; the fertilizers are usually applied after pruning has been completed.

In Hainan, China, NPK fertilizers are applied three times a year to mature trees in full bearing. These applications are generally given before flowering, after fruit set and after harvesting. The rates of application at each dressing are 0.25kg/tree, with an additional 0.5kg/tree of phosphate in the final dressing, given after harvesting. Farm-yard manure, at a rate of 20-25kg/tree, is also added to the final post-harvest fertilizer application (Yii, 1987).

Methods of application

Fertilizers are normally applied in a wide band around the margin of the tree canopy and they are normally mixed into the soil by a light cultivation. Dressings of fertilizer are normally followed by irrigation, except in wet weather.

Organic manures, usually in the form of a mulch, are regularly applied and renewed, particularly during the dry season and, in southern India, a top-dressing of 45-90kg of well decayed manure and 5-7 kg of groundnut cake is applied annually to each tree (Krishnamurthi and Rao, 1962).

Irrigation

Very little information has been published on the water requirements of mangosteen and, as has already been indicated in Chapter 3, the limited and generally weakly developed root system means that trees are quite sensitive to the level of water available in the soil. This may be particularly important during the early years of growth, when the root system is still relatively undeveloped.

The fact that vigorous, healthy trees have been observed growing alongside rivers and streams also indicates that the roots benefit from a relatively high soil moisture content and that trees are tolerant to short periods of water-logging. Conversely, they are probably very adversely affected by significant periods without rain or irrigation. As with rambutan (*Nephelium lappaceum*) and many other tropical crops, including coffee, the mangosteen has a requirement for a short dry period to initiate floral development (Chapter 3). It appears likely that this period should not exceed 2-3 weeks.

The general practice in South-east Asia appears to irrigate trees every two weeks during the dry season and it is considered that trees benefit from supplementary irrigation, even in relatively wet areas (Verheij, 1991). Heavy mulches are generally considered to be valuable in conserving soil moisture but irrigation is nevertheless considered to be required, even at small soil/water deficits.

Trickle irrigation, the use of micro-jet and low-angle sprinklers may all be considered as practical methods of applying irrigation and soluble fertilizers, included in the irrigation system, would appear to be an effective method of ensuring an adequate supply of both major and micro-nutrients.

Verheij (1991) has suggested that the harvesting period could possibly be shortened by briefly interrupting the irrigation schedule in order to initiate flower formation and consequently induce uniform flowering in commercial orchards. He has also emphasized that there remains considerable confusion over the effects of rainfall and the water requirements of mangosteen trees growing on various soil types in a range

of climatic conditions. Until more data are available in this area, therefore, it would appear that the traditional and locally applied methods in use should be continued.

Plate 10. Young tree with trickle irrigation system

CHAPTER 8. OTHER PRODUCTION PRACTICES

Weed Control

Under traditional mixed planting production systems, weed control is not considered to be a priority and, where mangosteens are planted under shade trees, weeds do not become a major problem. In some areas, grazing animals are often used to keep weeds under control and, in the southern Philippines, parts of Malaysia and southern Thailand, cattle commonly graze in mangosteen orchards. Young mangosteen seedlings, however, are very sensitive to weed competition and regular checks should be carried out to ensure that this does not occur. Dense mulches are an effective means of reducing weed infestation.

Where herbicides are available and their use is considered desirable, such as in commercial orchards, most annual and perennial weeds can be controlled by using glyphosate at a rate of 1.5-3.75 kg/ha active ingredient or, as a spot spray directed at individual weeds, at a rate of 150ml in 18 litres of water. Paraquat, which will kill the aerial portion of all types of weed, can be used, at a rate of 0.5-1.0kg/ha, preferably mixed with a surfactant to ensure adequate leaf cover. Plate 11 shows weed control by the use of herbicides.

Plate 11. Herbicide use to control weeds

Cover Crops and Intercropping

Weed eradication by the sowing of various crops around or between the mangosteen trees is a common practice when the trees are planted in an organized orchard or plantation production system. Since it may take 6-10 years before the trees bear fruits, the choice of the crop for a green manure, cover crop or cash crop generally depends on the objective of the grower. Cereals, coffee, papaya or water melon can be considered as alternatives to the more customary legume cover crops since they will provide a relatively rapid income for the grower. In Puerto Rico, mangosteen has been reported to be intercropped with pineapple.

Useful leguminous cover crops include *Crotalaria* spp., *Pueraria phaseoloides,* cowpeas, velvet beans and horse beans. These can be sown once the mangosteen trees have become established and should be resown every 3-4 years. Care should be taken to ensure that a distance of at least one metre around the base of the trees is kept free of cover crops and weeds since the mangosteen, in common with most other tropical fruit trees, is sensitive to competition, particularly during the early stages of growth. As the trees mature, the increasing size of the canopy will restrict weed and cover crop growth between trees.

Mulching

All trees, particularly young plants, will respond well to regular mulching, particularly during the dry season. Mulches restrict weed growth, maintain a relatively low soil temperature and prevent excessive soil moisture loss by evaporation. The breakdown of a mulch will also contribute to the organic content of the soil around the base of the tree. Mulches can consist of dried grass, weeds, coconut fronds, banana leaves or any available processing by-products such as coir, coffee or groundnut hulls. In Puerto Rićo, it has been customary to give young trees an annual mulch, at least 2.5cm deep, of well-decayed manure, applied towards the end of the rainy season (Winters, 1953).

Windbreaks

Mangosteen trees have a fairly compact and wide-angled branch structure and are therefore rarely subject to wind damage. However, in exposed conditions the leaves and fruits may be torn or bruised by strong winds and the presence of a windbreak is recommended where these conditions are likely to occur, such as in the Philippines where typhoons are prevalent. An additional risk is that strong winds will reduce the level of relative humidity around the trees; a high level of humidity has been observed to be essential for satisfactory growth to occur.

Windbreaks of rapidly-growing trees such as *Leucaena* spp., often known as *ipil-ipil* or *agoho*, *Casuarina* spp. or *Eucalyptus* spp. should be planted at right angles to the prevailing wind, at spacings of about 2m. These trees should be pruned early, to induce a dense, lateral habit of growth. They should not be planted closer than 6-8m from the nearest mangosteen tree, to avoid root competition.

Staking

Although mangosteen trees are generally sturdy, young seedlings, particularly those grown under shade, may require supporting by stakes. These are best inserted at the time of planting so that the root system will not be damaged; this could occur if the stakes were driven into the soil at a later date. Stakes should be at least 1m high and care must be taken to avoid the seedling rubbing against the stake by wrapping the trunk with a protective band of hessian or other available material where it is tied to the stake.

CHAPTER 9. HARVESTING AND POSTHARVEST TECHNOLOGY

HARVESTING

Flowering and fruiting periods in specific areas

Environmental and soil conditions have a significant effect on the growth and development of mangosteen trees, as they have on most tropical fruit crops. Climatic conditions, the height above sea level and the availability of shade can influence the period of flowering, sometimes leading to the production of two or even three crops per year; the period from flowering to maturity is also variable in different geographical areas. Biennial bearing has been reported to occur in several areas but there is a possibility that this variation in fruiting may be due to environmental conditions, not to an inherent tendency to on-off fruiting periods.

In general, mangosteen seedlings require from 6-10 years to come into bearing but, under very favourable conditions, this may be reduced to 4-6 years, particularly if the trees are vegetatively propagated.

The following data, from various sources, illustrate these variations:

<u>Thailand</u>

Most trees in southern Thailand begin to flower in the sixth year from planting and maximum fruit yield is usually attained after 12 years. The period from flowering to harvesting is generally 11-12 weeks. The trees normally flower from December to February and are harvested from April to June. The actual flowering period usually lasts for about 40 days, resulting in a relatively extended harvesting period.

<u>Malaysia</u>

The main harvesting season in Malaysia is usually from June to August, but this period is variable since flowering is linked with the onset of the dry season. The timing of the harvesting period also appears to be considerably influenced by altitude and shade. A small second crop is

frequently produced in Malaysia in November/January. Older, mature trees tend to bear in alternate years. The main harvesting period in Sarawak is from November to January.

Philippines

Trees planted under coconut shade are reported to bear fruit 4 years from planting in some areas and flowering normally begins in March/April. The fruiting season normally extends from June to December but is variable and depends on the geographical position of the orchard.

Myanmar (Burma)

Fruits are produced in the lowland areas from November-January and April-July, the main production occurring in May and June.

India

In the Madras area, the main flowering periods are April-May and October-November with fruits being harvested in July-October and January-March (Krishnamurthi et al., 1964).

Sri Lanka

At low elevations, the harvesting period extends from May to July but, at an elevation of 500m, it is from September to October.

Australia

In northern Australia, the major harvesting period is February/March, with a smaller crop in November/December (Wiebel et al., 1992).

Ivory Coast

The flowering periods are February-March and June-August, following after vegetative flushes in December-January and June-July; fruits are normally harvested 125-150 days after flowering.

Madagascar

Four vegetative flushes occur each year and harvesting follows three months after flowering. The main cropping periods are February-May and October-December (Bordeaut and Moreuil, 1970). Trees often show a tendency towards biennial bearing although some trees bear consistently high yields (Krishnamurthi et al., 1965)

Puerto Rico

In Mayaguez, harvesting occurs during July/August if the trees are not shaded and from November-December when the trees are grown in shade. At differing elevations, trees have been reported to produce 2 crops a year: a light crop in January from flowers produced in August/September and a heavy crop in July and August from flowers produced in January/February (Almeyda and Martin, 1976).

Trinidad

The two main fruiting seasons appear to be July and October (Bailey, 1963).

Harvesting criteria

A post-harvest study on mangosteen ripening, carried out in Indonesia, showed that the longest shelf-life of 9 days was obtained when fruits were picked at the stage when uniform purple patches covered approximately a quarter of the fruit pericarp (Harjadi et al., 1989). Another study confirmed that the optimum time for harvesting was when 25% of the fruit skin had developed a purple colour. Such fruits ripened normally in one day, when stored at ambient temperature, after detachment from the tree (Daryono and Sosrodiharjo, 1986).

Commercial maturity was studied in Indonesia by Sosrodiharjo (1980) and he considered that the maximum physical growth of fruits was reached 103 days from full bloom, when pulp acidity had attained its highest value and red patches were apparent on the skin. Fruits which were picked after 90 days, at the green mature stage, ripened normally at ambient temperature; the skin softened after 14 days, accompanied by a slight colour change, but the fruits eventually became similar to fruits ripened on the tree.

An appreciation of the various stages of ripeness of mangosteen fruits enables growers to harvest at the optimum stage of maturity for the domestic or export markets. In Thailand, the Institute of Industrial, Scientific and Technological Research (TISTR) has developed a colour chart to guide mangosteen growers; this is illustrated in Plate 12 and this chart has assisted Thai producers in the export of good quality fruits (Pungsuwan, 1989).

Growers normally harvest only the fruits which have turned purplish violet according to the colour chart. Harvesting fruit before the optimum harvesting maturity has been reached is associated with an excessive flow of latex at the point of fruit detachment. Latex causes stains on other fruits and, in order to avoid this, fruits should not be harvested before they reach stage 2. As maturity increases, the fruit susceptibility to mechanical damage increases. Fruits at stage 5, for example, are unable to withstand a compression force of 6kg (Tongdee and Sunwanagul, 1989).

Harvesting operations

Fruit damage at harvest

A fully mature fruit will drop from the tree and, if it lands on a layer of leaves, cover crop or weeds, it will probably remain in a good condition. If, however, it lands on a hard surface, such as bare soil, it will sustain serious damage.

Although the mangosteen has a relatively thick pericarp, it needs to be handled with care to prevent it becoming damaged or "cracked". Cracking causes the exudation of yellow latex and a rapid hardening of the affected part of the pericarp. Mechanical damage to the pericarp is clearly visible

Colour stage 0.

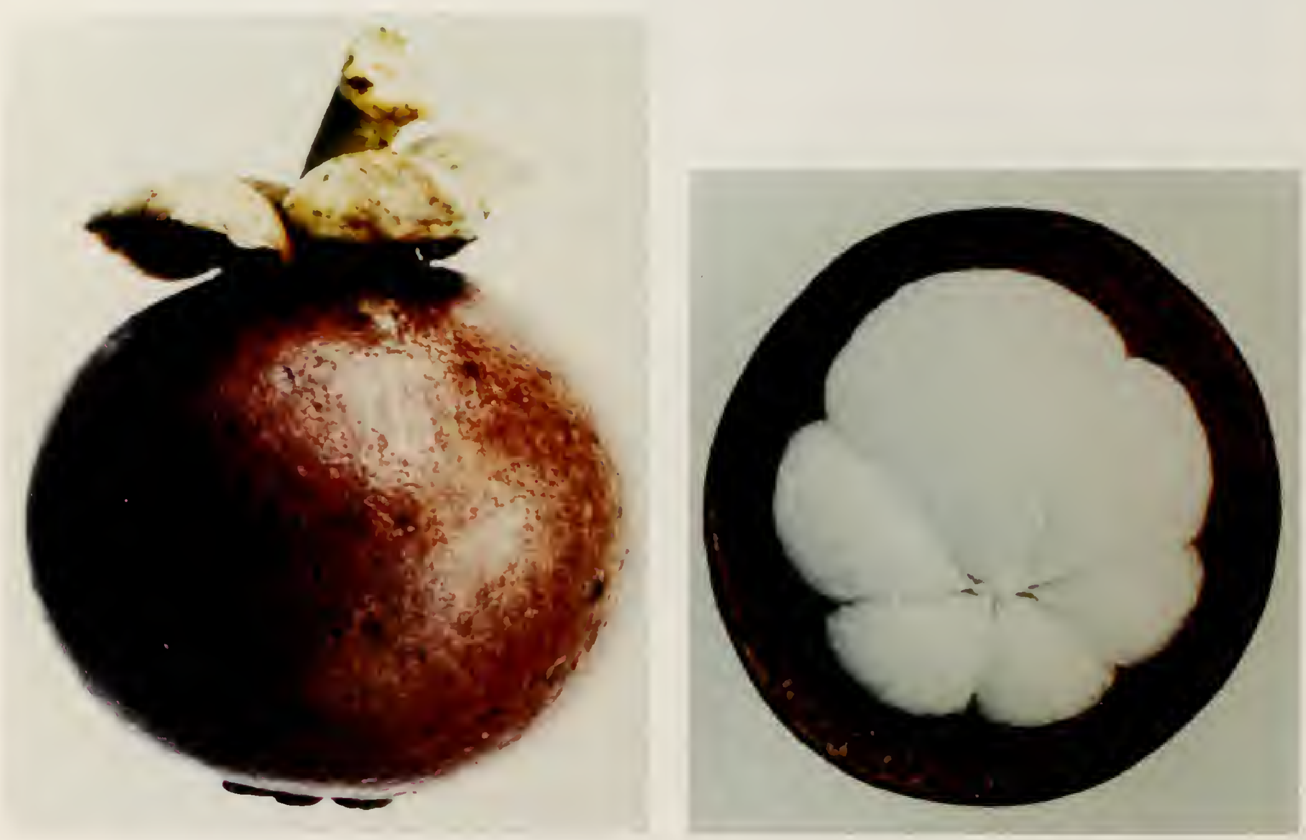
Pericarp uniformly yellowish white or yellowish white with a light green tinge or greyish spots. Yellowish latex in pericarp very plentiful. Pericarp and aril not separable. Fruits harvested at this stage eventually darken to stage 6 and are of inferior flavour.

Colour stage 1.

Pericarp light greenish yellow with scattered pinkish spots. Latex in pericarp plentiful. Pericarp and aril do not separate. Fruits harvested at this stage eventually darken to stage 6 and are of inferior flavour.

Plate 12. Colour chart ripening guide for mangosteen fruits, Thailand.

Colour stage 2 Pericarp light pinkish yellow with distinct irregular pink-red spots covering entire fruit. Latex in pericarp moderate. Minimum harvesting stage of quality fruit.



Colour stage 3 Pericarp background uniformly pinkish, spots not as distinct as in stage 2. Latex in pericarp slight. Suitable stage for export handling.

Plate 12. Colour chart ripening guide for mangosteen fruits, Thailand.

Colour stage 4
Pericarp red or reddish brown, some with purple tinge. Latex in pericarp very slight to none. Pericarp readily separates from aril. Suitable stage for export handling. Fruit almost ripe.

Colour stage 5
Pericarp darkened to reddish purple. No latex remains in pericarp. Complete and easy separation of pericarp and aril. Fruit fully ripe.

Plate 12. Colour chart ripening guide for mangosteen fruits, Thailand.

to the naked eye. The damaged portion of the pericarp hardens within 24 hours, causing the collapse of the underlying aril tissue. Dehydration rapidly follows and the fruit turns brown (Tongdee and Suwanagul, 1989); this reduces the fruit quality, rendering it unattractive.

Studies in Indonesia showed the effect of fruit-drop at harvesting on fruit quality. Observations on 150 fruits at 3 ripening stages showed that immature mangosteen fruits are very sensitive to mechanical force, causing the pericarp latex to enter the aril, resulting in an unacceptable and inferior quality. The most sensitive fruits are those which are at the purple stage since the volume of yellow latex present in the fruits gradually reduces as the fruits mature.

Hand harvesting

If fruits are to be sold in either local or export markets, the fruits should be picked just before they fully ripen, using a device for catching the fruits. Hand-picking is essential since the pericarp, which is still slightly soft at this stage, will be likely to be damaged if it falls; fruits should always be harvested with the peduncle attached. For hand harvesting, ladders are required for taller trees. An alternative method, if hand harvesting is not possible, is to use a long pole with a hook and a basket attached at the end to catch the fruits, such as are sometimes used for mango harvesting. Bamboo poles, with a V-shaped fork at the top for detaching single fruits are used in Malaysia but, in orchards in eastern and southern Thailand, ladders and picking baskets are preferred.

The high cost of harvesting, due to the extended ripening season, appears to be a major constraint to the commercialization of the crop at the present time. At the high prices which the fruits reach on the international markets, hand harvesting with ladders and baskets is still, however, an economic method for the efficient producer. Growers do not normally take the risk of leaving the fruits on the tree until they are mature but harvest them when the colour changes. Since the fruits on any particular tree ripen over a period of more than 2 months and since the intervals between harvests are usually quite extensive, many fruits are harvested when they are too immature, resulting in poor quality produce arriving at market outlets.

Yields in various areas

It has already been emphasized that flowering and fruiting periods may vary quite considerably in different geographical areas and this variation is also reflected in the yields obtained. Since the mangosteen has a narrow genotypic base, these differences are presumed to be mainly due to soil and environmental factors, particularly elevation. The estimated yields in various producing areas are as follows:

Malaysia

The yield of mature, bearing trees was estimated to vary widely, from 200-2,000 fruits per tree, over a 15-18 year period. Average yields of 200-300kg/tree, exceptionally reaching 500kg/tree, have been suggested (Abidin, 1990).

Thailand

Yield data from selected areas in Thailand, for 1981, indicated a yield of 5-8t/ha per season; for 1987, the average yield was considered to be 4.5t/ha (Verheij, 1991). For an estimated mean weight of 75g per fruit and at a planting density of 150 trees/ha, this is equivalent to 400 fruits per tree per annum. In the 1988/89 season, the eastern and southern regions produced a combined total of 77,350t of fruits from a planted area of 11,700ha.

Puerto Rico

A yield of 500-1500 fruits per tree has been reported by Almeyda and Martin (1976)

Southern India

Trees in two small orchards in the Nilgiri hills in southern India produced an average of 360 fruits per year over a period of 18 years. A yield of 200-300kg per tree is normally obtained although a yield of 500kg per tree has been reported.

Plate 13. Freshly harvested fruits in picking crates and cane baskets

Plate14(a). Fruits packed in woven cane baskets

Plate 14(b). Fruits in bundles of 10-15 fruits, Malaysia

Plate 15(a). Mangosteen fruits in traditional baskets

Plate 15(b). Packing mangosteen fruits for export into cardboard boxes, Thailand

Sri Lanka

A light crop is estimated to be 100 fruits per tree, while a heavy crop may be 500-600 or more fruits per tree. Yields of 200-800 fruits per mature tree have been reported from areas with good soils.

The wide range of yields quoted by various authorities indicates that the mangosteen is quite sensitive to variations in soil and climatic conditions, as far as yields are concerned. It is also possible, however, that many quoted yields are rough estimates from relatively few trees and that more definitive assessments may produce results which differ appreciably from those commonly quoted.

POST HARVEST TECHNOLOGY

Handling, Grading and Packing

Local markets

After they have been harvested, the fruits which are to be sold in local markets are packed in large, locally made cane baskets which can normally hold up to 30kg of fruit (Plate 13(a)). Fruits may also be washed in cold water shortly after harvesting; this also serves to reduce the respiration rate.

Fruits may be hand-graded in a packing shed before being placed in the baskets, at which stage any mis-shapen or damaged fruits are removed. Damage should be limited by avoiding pouring the fruits from one container to another. Mangosteen grading machines have been designed for sorting fruits according to their weights, but are still in the experimental stage (Jarimopas et al., 1988; Tongdee and Suwanagul, 1989). The fruits are graded by this prototype grader into three groups: over 100g, 75-100g and below 75g. The machine can grade up to 1.1t per hour and has an efficiency of approximately 80%. The power requirement is about 0.2kW per hour.

Although mangosteens are often sold in the local markets as individual fruits, usually according to their weight, they may also be tied in long

bundles. In Malaysia, there are 10-15 fruits/bundle (Plate 14(b)) and in Thailand 20-25. This method of tying is also used in Indonesia and the Philippines where about 24 fruits are tied in a bundle.

Export markets

The tough, thick rind of the fruits enables them to be shipped over long distances in a good condition. The mangosteen fruit is unique because, as it matures, the rind becomes very hard. Recommendations have been made for dipping the fruits in a copper-based fungicide before packing them for export (Almeyda and Martin, 1976) but there are few other references to the adoption of this treatment.

For long distance transport, only fruits which are without any dark skin colouration or red lines, which are known as "blood vessels" in Thailand, and which are free from pests and diseases should be selected. The fruits are first washed with water and are then graded according to their size and colour before they are packed into a 38 x 25 x 7.5cm (15 x 20 x 3 in) cardboard box; each fruit is sometimes individually wrapped with tissue paper. Each box has holes to allow for ventilation and contains 24-30 fruits (Plate 15). It is generally considered that fruit size does not seriously affect the quality of the aril. Small fruits are usually preferred since they have fewer seeds and contain only 1-2% less edible aril than larger fruits.

Trials with mangosteen fruits for export by air freight were reported to have been successful when the fruits were packed in 5kg cardboard cartons with a polyethylene lining and with humidifier pads enclosed in the cartons (Anon, 1987). The cartons were kept at 13°C for several days before being exported from Thailand to Hong Kong. The fruits were in good condition on arrival and maintained a good quality level for up to 6 days at ambient temperature.

Contamination in transit due to disease is not a significant problem, due to the hardness of the rind, and it is relatively easy to detect decaying fruits.

Postharvest fruit damage

Tongdee and Suwanagul (1989), in their investigations on postharvest losses in mangosteen, used various tests to identify the various forms of damage incurred by harvested fruits. These tests included a number of compression forces, fruit rupture force and impact damage, which was assessed by a fruit drop test.

They found that the resistance of fruits to compression forces reduced as fruit maturity increased; a compression force of 3-4kg caused very slight damage to the fruit but, in more mature fruits, a force of 5kg caused pericarp collapse. The rupture force decreased from more than 100kg for unripe fruit to about 8kg for mature fruit.

Impact damage, expressed as a hardening of the pericarp at the point of impact, increased from slight damage with a drop of 10cm to both pericarp and aril damage at a drop of 20cm or more. When fruits were packed in columns which were 2, 3 or 5 fruits high, most damage was incurred by the lowest fruits. The authors therefore concluded that mechanical damage to mangosteen fruits can be readily reduced by using care in handling to avoid compression or impact damage.

Storage

In general, tropical fruits have a shorter storage life than most temperate fruits. With the advancement in post-harvest technology in recent years, the storage of fruits has become more widely used. Cold storage and controlled atmosphere storage techniques have been developed for application in the fruit industry and are mainly used for high value fruits intended for export. Table 7 illustrates the storage life and weight loss of selected tropical fruits at varying temperatures and 85-90% relative humidity.

Storage facilities which provide for the controlled temperature and controlled atmosphere storage of tropical fruits are very costly to install and operate and may only be justified for use with high quality fruits that have been graded and selected. Fruits which are to be stored in cold stores and controlled atmosphere stores should be subjected to a pre-

cooling treatment beforehand, usually by immersion in cold water, to reduce the rate of respiration (Table 8).

Table 7. Storage life of selected tropical fruits under controlled storage conditions

Fruit	Temperature °C	Relative humidity (%)	Storage life (weeks)	Weight loss[1] (%)
Durian	4.5	85-90	7	-
Jackfruit	11.5	85-90	6	-
Langsat	12.7	85-90	2	24.3
Lychee	2.0	85-90	10	-
Mango	8.3	85-90	3	5.1
Mangosteen	**4.5**	**85-90**	**7**	-
Papaya	8.3	85-90	2.5	5.8
Rambutan	10.0	85-90	2.5	5.8
Santol	8.0	85-90	3	-
Sapodilla	2.0	85-90	2	-

[1]Weight loss determined at the end of storage life

Table 8. Respiration rates and ethylene production of selected fruits stored at 25°C

Fruit type and cultivar	CO_2 released (ml $kg^{-1}hr^{-1}$)	C_2H_4 released (ml $kg^{-1}hr^{-1}$)
Durian		
Kan Yaw	117.94-237.91	10.77
Chanee	89.96-214.50	6.43
Mon Thong	56.37-208.31	9.52
Mangosteen	**10.95**	**29.22**
Rambutan		
Sri Chompoo	24.67-56.00	2.00
Rongrian	29.35-56.67	2.60

Source: Kosiyachinda (1986).

The mangosteen is a climacteric fruit and, as can be seen from Table 8, produces considerably more ethylene than either durian or rambutan when stored at 25°C although the rate of carbon dioxide production is much lower. It is therefore essential to keep the fruits in low temperature conditions to reduce the rate of ripening. The climacteric peak in respiration is normally reached about 10 days after the fruits have been placed in storage (Nagy and Shaw, 1980).

Storage temperatures

Raman et al. (1971) reported that, at a room temperature of 27-30°C, at a relative humidity of 50-60%, 30% of mangosteen fruits were spoiled after 10 days and 100% were unfit for consumption after 20 days; storage at 4.5-7.0°C gave the best results with 38% spoilage after 30 days. Martin (1980) also indicated that fruits could be stored for 2-3 weeks at room temperature. The optimum storage temperature was considered by Srivasta et al. (1962) to be between 4°C and 6°C, at which temperatures fruits could be stored for up to 49 days.

The effects of different storage temperatures on the physical characteristics of mangosteen have been investigated more recently by Augustin and Azudin (1986). Commercially mature fruits were placed in plastic baskets and stored at 4°C, 8°C and ambient temperature, 26°C. The fruits were evaluated at intervals during the storage period and were assessed on appearance and quality. Fruits stored at 4°C and 8°C showed an extended storage life, compared with those kept at 26°C, the main changes being a hardening and browning of the pericarp and browning and loss of lustre and texture of the flesh segments; the segments of fruits stored at 4°C and 8°C for 44 days had a slightly fermented smell and flavour but a significant percentage, ie. 75% of fruits stored at 8°C, was still of an acceptable eating quality.

At room temperature, where the rate of hardening of the pericarp was similar to the rate of deterioration of the flesh segments, only 30% of the fruits were of an acceptable quality after 15 days of storage. They concluded that, although storage temperatures of between 4°C and 8°C can be used to prolong the shelf life of mangosteens, the major problem in mangosteen storage at low temperatures remains the hardening of the

pericarp which reduces the overall consumer acceptability of the fruit due to the difficulty in cutting open the pericarp.

Biochemical changes during storage

The chemical composition of mangosteen fruits has already been described in Chapter 2; the chemical changes taking place in fruits during storage have also been investigated in detail by Augustin and Azudin (1986). They found that the total soluble solids (TSS) varied between 17.7 and 20.4° Brix and the titratable acidity ranged from 1.69 to 2.15ml 0.1N NaOH/ml juice. These changes were not considered to produce any real alteration in the flesh flavour.

The TSS increased in fruits stored at room temperature and 8°C and titratable acidity was found to decrease with increasing length of storage time; these changes had already been indicated by Raman et al. (1971), who had found that, during storage, fruits showed a slight increase in TSS and a decrease in titratable acidity.

Daryono and Sosrodiharjo (1986) also found that, at harvest, the sugar content was 14.3%, the acidity 0.46% and the vitamin C content 42.3mg/100g.

Augustin and Azudin (1986) also confirmed the earlier findings of Kawamata (1977) that the major sugar content of the mangosteen is in the form of fructose, glucose and sucrose and found that the total content of these sugars was 18g/ml^{-1} of juice. Based on the marked correlation between the TSS and the total sugar content, also the similarity between these two values, they suggested that almost all the total soluble solids in the juice of the flesh segments are in the form of glucose, fructose and sucrose.

The fructose and glucose contents increased during storage at all temperatures and the fructose/glucose ratio varied in the fairly narrow range of 0.89 to 1.17. The sucrose content decreased during storage at 4°C but remained relatively constant in fruits stored at higher temperatures.

Augustin and Azudin (1986) considered that a number of factors, including storage temperatures, affect not only the rate of formation of sugars in the mangosteen fruit, but also the degree of interconversion between the component sugars and the rate and extent of utilization of individual sugars. They also suggested that it was likely that any intrinsic variability which could exist between mangosteen clones from different sources may be reflected in the variability which could be observed in the content of the individual component sugars during storage.

The volatile constituents of the mangosteen fruit, which contribute to the characteristic aroma, were investigated by MacLeod and Pieris (1982), using gas chromatography/ mass spectrophotometry. The volatile yield was found to be relatively small, compared with that produced by other fruits, and amounted to about 3µg/kg of fresh fruit. It was considered that the aroma was largely due to the presence of hexyl acetate and *cis*-hex-3-enyl acetate. The authors also identified six sesquiterpenes.

Weight loss during storage

Experiments carried out in Indonesia by Daryono and Sosrodiharjo (1986) have shown that fruits stored for 7 days in ambient temperature lose 3.3% of their weight; these fruits also show a disease level of 23.9%. Fruits at ambient temperatures, enclosed in polyethylene bags lost 2.3% of their weight and had a disease level of 13%. Storage in plastic bags slightly reduced the sugar:acid ratio but had no effect on the vitamin C content. At 5°C, the weight loss was 0% and the percentage of diseased fruit was 11%. Cold storage caused no chilling injury and had no adverse effect on fruit quality.

Commercial storage

Fruits stored in cardboard containers in normal room temperature can maintain fruit quality for up to four weeks and storing ripe fruits at temperatures of 4°C to 8°C can prolong their shelf life.

A temperature of 13°C has, however, proved to be suitable for storing mangosteen to maintain a high standard of quality; the ideal transit temperature is considered to be in the range 13-25°C. Fresh fruits can be

marketed for up to 21 days after harvest, provided that some form of cold storage is available. Due to the thickness of the pericarp layer, fruits generally remain in good condition during transit.

CHAPTER 10. PESTS, DISEASES AND NON-PATHOGENIC DISORDERS

Crop protection

Compared with most other tropical fruit crops, mangosteen is affected by few insects and diseases. The relatively thick skin of the fruit and the leathery texture of the mature leaves of mangosteen are characteristics which deter both insects and fungi from affecting the crop; the records of pest and disease incidence on mangosteen are therefore relatively few and many pests and diseases follow the same species pattern in the main growing areas.

No integrated pest control measures appear to have been adopted for mangosteen, probably due to the low incidence of pests and diseases. As commercial and medium-scale orchards become more popular, however, such measures will become necessary, with an emphasis on a reduction in the level of pesticides to reduce costs and meet the requirements for conserving the environment and the prevention of chemical residues in harvested crops.

Since there are very few commercial orchards, no large-scale crop protection strategies and equipment have been designed for mangosteen orchards; any machinery used, therefore, is that which is also in use with other tropical tree crops.

The main equipment used, in both small-scale and commercial orchards, are shoulder-mounted sprayers, sometimes motorized but mainly hand-operated. Extension lances may be used for spraying the taller, more mature trees. Powder dusters are occasionally used in some areas. The chemicals used are generally those which are locally available.

Natural Protectants

Although no commercial applications have yet been reported, it is known that the fruit of mangosteen contains a xanthone, mangostin, which, together with its several derivatives, has been found to be highly effective against both bacteria and fungi (Sundaram et al., 1983). The fungi

affected included: *Mucor* spp., *Rhizopus* spp., *Aspergillus flavus* and *Penicillium* spp..

Pests

Ants. A common pest, reported from Puerto Rico and elsewhere, is a small ant, *Myrnelachista ramulorum* Wheeler. These ants, which have a yellow thorax and blue-black head and abdomen, live in large colonies in the tree branches and in old, decaying stumps. They bore long, irregular tunnels through the central trunk of the tree and these may also extend into the living branches, causing withering of the growing points. Plants are sometimes stimulated to develop a mass of dense foliage.

Some control can be obtained by pruning dead branches, removing old stumps and spraying the colonies with malathion.

Thrips (*Thrips* spp.), red spider mite (*Tetranychus* spp.) and other species of mite have been reported to infest flowers and damage the fruit surface, making it unsuitable for export. These pests are normally sprayed with flowers of sulphur powder or carbaryl or organo phosphates.

The tussock caterpillar (*Eupterote favia* Cramer) has been reported from the Philippines, where it feeds on the leaves.

Scales are frequently found to infest mature plants. The coconut scale (*Aspidiotus destructor* Sig.) forms colonies on the lower surface of the leaves, causing yellow patches to develop and generally reducing vigour.

Longhorn grass-hopper (*Onomarchus leuconotus* Serv.) is a pest of mangosteens in Malaysia. Adults lay eggs on the branches and the larvae feed on the soft tissues inside the branch. In severe infestations, infected branches may show a serious loss of vigour.

Yellow beetles (*Hypomeces squamosus* F.). These leaf-chewing insects have been reported from northern Malaysia. In serious infestations, the new leaves produced during a flush may be severely damaged.

Bats, rats, squirrels and monkeys. These mammalian pests can inflict severe damage to trees and fruits, particularly in rural areas. Rats, bats and crows have been reported to be serious pests in Sri Lanka where they damage fruits in some areas. Methods of reducing damage by these pests include maintaining strict orchard hygiene, trapping and the use of approved chemical poisons.

Nematodes. Published reports on nematode infestation of mangosteen roots are very limited but it has been observed by Chawla et al. (1981) that *Tylenchulus semipenetrans* Cobb., the citrus nematode, has been found to be present on roots of mangosteen trees grown in Tamil Nadu, India. Adult females were found attached to the roots and larval stages were encountered in the soil around the roots. The effects of this infestation on the growth of the trees are not known.

Diseases

Brown root rot (*Phellinus noxius* (Corner) G.H. Cunn.) and Red root rot (*Ganoderma* sp.) have been reported from Malaysia and may become economically serious (Singh, 1973). Both diseases result from an infection of roots through contact with spores from decaying stumps of crops such as oil palm.

Root lesions may develop on the trunk followed by a wilting of the foliage. Control consists mainly of removing or burning old trunks of felled trees; Brown root lesions may be treated with a fungicide.

Thread blight (*Corticium (Pellicularia) koleroga* Cooke) has been reported to be a common disease in Puerto Rico; it is also found on coffee, cocoa and the rubber tree (*Hevea brasiliensis*). Factors which promote the spread of this disease are high humidity and dense shade. The symptoms include infections of leaves, young branches and young fruits in the form of spots which gradually enlarge; fruits and leaves may be covered with a fine web of filaments. Infected leaves become brown or black and absciss from the tree although they remain suspended by the filamentous web. Spraying with copper-based fungicides is generally effective. Removal of shade plants and improved drainage, with the objective of reducing the humidity of the area, may also be effective.

Stem canker (*Zignoella garcineae* P. Henn.). In Malaysia, this fungus has been observed to promote the formation of galls on young stems, these persist on mature branches where they eventually cause the death of infected wood. In serious infections the tree may die and it is recommended to cut out and burn infected trees to prevent spread of the disease.

Postharvest diseases include: *Botryodiplodia theobromae* Pat., *Diplodia* sp., *Gloeosporium* spp., *Pestalotia flagisettula*, *Phomopsis* spp. and *Rhizopus* spp. These usually result in the hardening of the pericarp and the decay of the aril.

NB. The use of extremely hazardous and highly hazardous pesticides (according to the current World Health Organization classification) such as captafol, dicrotophos, methomyl and monocrotophos is not recommended.

Moderately hazardous pesticides, including carbaryl, chlordane, chlorpyrifos, dimethoate and formothion should only be used where their safe use can be guaranteed.

Physiological disorders

Gamboge disorder is a physiological disease, the symptoms of which are the hardening of the fruit pulp, which later turns reddish brown, while the pericarp and aril are both discoloured by a yellow resin; the aril also becomes bitter in taste. Yellow spots may also develop on the fruit skin. Affected branches and fruit both exude a yellow resin which is responsible for the discoloration and change in taste. This disorder may be caused by excessive rain, winds and careless handling which induce physical damage to the fruit pericarp and also to some types of pest infestation, particularly by capsids. The establishment of shelter belts may reduce wind damage (Bordeaut and Moreuil, 1970).

Fruit cracking may occur during wet weather, due to an excessive intake of water over a short period; fruits show swollen and softened flesh.

Leaf sunburn may occur when the humidity is lower than 60% and the temperature higher than 35°C. The main effect is a depression in growth and yield (Hackett and Carolane, 1982).

Magnesium deficiency has been recorded in some areas (Marchal, 1972). Deficient leaves showed a magnesium content of 0.105%, compared with 0.150% in healthy leaves. The symptoms are generally inter-veinal chlorosis, often beginning in older leaves.

Zinc deficiency has been observed to cause "little leaf" symptoms, presumed to be due to an imbalance between the iron and zinc contents of leaves (Marchal, 1972).

Bibliography

Abidin, M.I. (1990). Cultivation of tropical fruits. Hi-Tech Enterprise, Kuala Lumpur, Malaysia: 86-90.

Alexander, D. McE., P.B. Scholefield and A. Frodsham (1982). Some tree fruits for tropical Australia. Commonwealth Scientific and Industrial Research Organization, Australia.

Almeyda, A.N. and F.W. Martin (1976). Cultivation of neglected tropical fruits with promise. 1. The Mangosteen. Agric. Res. Service, USDA, Washington

Anon (1961). Fruit crops in Thailand. Min. of Agric., Bangkok.

Anon (1987). Exporting Thai mangosteen and rambutan to Hong Kong. ASEAN Food Handling Newsletter 23:6-8.

Augustin, M.A. and M. N. Azudin (1986). Storage of mangosteen (*Garcinia mangostana* L.) ASEAN Food Journal 2(2):78-80.

Avadhani, P.N. (1984). Physiological studies on the shelf-life extension of tropical fruits. Food Irradiation Newsletter 8(2):18.

Bailey, L.H. (1963). The standard cyclopedia of horticulture. Macmillan, New York.

Balasubramanian, K. and K. Rajagopalan (1988). Novel xanthones from *Garcinia mangostana*, structures of BR-xanthone-A and BR-xanthone-B. Phytochemistry 27(5):1552-1554

Bennett, G. and H.H. Lee (1989). Xanthones from Guttiferae. Phytochemistry 28(4):967-998.

Bourdeaut, J. and C. Moreuil (1970). Le mangoustanier, ses possibilités de culture in Côte d'Ivoire et à Madagascar. Fruits d'Outre Mer. 25:223-245.

Brown, W.H. (1936). Wild food plants of the Philippines. Bull. Bur. For. Philipp. Is, 21.

Buisson, D. (1986). Analyse architecturale de quelques especes d'arbres fruitiers tropicaux (Architectural analysis of some species of tropical fruit trees). Fruits 41(7/8):477-498.

Burkill, I.H. (1966). A dictionary of the economic products of the Malay Peninsula. Min. of Agric. and Co-operatives, Kuala Lumpur, Malaysia.

Campbell, C.W. (1967). Growing the mangosteen in southern Florida. Proc. Fla. St. Hort. Soc., 1966, 79:399-401.

Chan, Y.K., S. Hassan, S.H. Jamaluddin, P. Raveendranathan, A. Hussein, M. Salleh, M. Rahman and L.T. Tan (1982). A report on the techno-economic survey of the Malaysian fruit industry 1980. (eds: Mohd. Yusof Hashim and Mohd. Ariff Hussein). MARDI-UPM, Malaysia.

Chau Kay-Ming (1990). Mangosteen. In: Fruits: Tropical and subtropical (eds. T.K. Bose and S.K. Mitra). Naya Prokash, Calcutta, India: 781-784.

Chawla, M.L., G.J. Samathanam and S.B. Sharma (1981). Occurrence of citrus nematode (*Tylenchulus semipenetrans* Cobb) on roots of mangosteen (*Garcinia mangostana*). Indian Journal of Nematology 10(2): 240-242.

Chin, H.F. (1978). Production and storage of recalcitrant seeds in the tropics. Acta Horticulturae 83: 17-21.

Chin, H.F. and E.H. Roberts (1980). Recalcitrant crop seeds. Tropical Press Sdn. Bhd., Kuala Lumpur, Malaysia.

Chong, S.T. and O. Azizan (1984). Teknik pembiakan manggis - cantuman biji. Technol. Pertanian MARDI, Malaysia. 5:174-177.

Chong, S.T. and T.B. Chai (1986). Recent developments in vegetative propagation of some tropical fruit trees. Proc Symp. Buah-buahan Keb., Serdang, Malaysia (1986): 236-250.

Cobley, L.S. (1956). An introduction to the botany of tropical crops. Longman, London.

Corner, E.J.H. (1952). *Garcinia mangostana* L. . In: Wayside trees of Malaya. Vol.1. 2nd ed., Govt. Printing Office, Singapore: 312-320.

Cox, J.E.K. (1976). *Garcinia mangostana* - mangosteen. The propagation of tropical fruit trees. Horticultural Review No.4. Commonwealth Bureau of Horticulture and Plantation Crops, East Malling, Kent, England: 361-375.

Crisotomo, L.C. (1977). Preservation of fruits and vegetables. Bureau of Plant Industry. Manila, Philippines.

Daryono, M. and S. Sosrodiharjo (1986). Cara praktis penentuan saat pemanenan buah manggis dan sifat-sifatnya selama penyimpanan (Practical methods for harvesting mangosteen fruits and their storage characteristics) In: Indonesia Buletin Penelitian-Hortikultura, Indonesia. 14(2):38-44 (with English summary)

Dassanayake, E.M. and W.G.S. Perera (1988). No true seed, no fertilization: wedge grafting of mangosteen. Indian Horticulture 34(2): 10-11..

Downton, W.J.S., W.J.R. Grant and E.K. Chacko (1990). Effect of elevated carbon dioxide on the photosynthesis and early growth of mangosteen (*Garcinia mangostana* L.). Scientia Horticulturae 44:215-225.

Du, C.T. and F.J. Francis (1977). Anthocyanins of mangosteen, *Garcinia mangostana*. Journal of Food Science 42(6):1667-1668.

Fielden, G.St. C. and R.J. Garner (1936). Vegetative propagation of tropical and sub-tropical fruits. Tech. Comm. Imp. Bur. Fruit. Prod. No. 7.

Food and Agriculture Organization (1990). Utilization of tropical foods: fruits and leaves. FAO Food and Nutrition Paper 47/7. Food and Agriculture Organization, Rome.

Food and Nutrition Center (1968). Food composition tables. Food and Nutrition Center, Manila, Philippines.

Gaillard, J.P. (1978). Studies on tropical fruits (other than bananas, pineapples and citrus). Fruits 33(9):543-665 (in French).

Goh, H.K.L., A.N. Rao and C.S. Loh (1988). *In vitro* plantlet formation in mangosteen (*Garcinia mangostana* L.). Annals of Botany 62(1):87-93.

Goh, H.K.L., A.N. Rao and C.S. Loh (1990). Direct shoot bud formation from leaf explants of seedlings and mature mangosteen (*Garcinia mangostana* L.) trees. Plant Science 68:113-121.

Gonzalez, L.G. and Q.A. Anoos (1951). The growth behavior of mangosteen and its graft-affinity with some relatives. Philipp Agric. 35:379-95.

Hackett, C. and J. Carolane (1982). Edible horticultural crops. Part 1. Academic Press, London

Halijah Ibrahim (1989). Several *Garcinia* species of Penang Island. Nature Malaysiana 14(1):28-31.

Harjadi, S.S., A. Hidayat and M. Argasasmita (1989). Eco-physiological study and post-harvest handling of mangosteen fruits (*Garcinia mangostana* L.).

Horn, C.L. (1940). Stimulation of growth in juvenile mangosteen plants. J. Agric. Res. 61:397-400.

Horn, C.L. (1941). Existence of only one variety of cultivated mangosteen explained by asexually formed "seed". Science 92:237-238.

Hume, E.P. (1950). Difficulties in mangosteen culture. Malayan Agriculture Journal 33(2):104-7.

Hume, E.P. and M. Cobin (1946). Relation of seed size to germination and early growth of mangosteen. Proc. Amer. Soc. Hort. Sci. 48:289-302.

Husin, A. and D. Chinta (1989). Fertilizer supply and needs for food and fruit crops in Malaysia. In: Soil management for food and fruit crop production. (eds. Wan Noudin and Wan Sulgiman). Soil Sci. Soc., Malaysia. p.121-137.

Hutabarat, B. (1989). Issues and strategies for developing the Indonesian horticultural subsector, IARD Journal II:5-13.

IBPGR (1986). Genetic resources of tropical and sub-tropical fruits and nuts (excluding *Musa*). International Board of Plant Genetic Resources, Rome.

Idris, S. and A. Rukayah (1987). Description of the male mangosteen (*Garcinia mangostana* L.) discovered in Peninsular Malaysia. MARDI Res. Bull. 15(1):63-66.

IFAC (1967). Rapport Annuel. 1966-667. Institut Francais de Recherches Fruitières Outre-Mer, Paris:204.

Jansen, P.C.M. (1991). *Garcinia* L. In: Edible fruits and nuts. Plant Resources of South-East Asia 2. (eds. Verheij, E.W.M. and R.E. Coronel) PROSEA. Pudoc, Netherlands.

Jarimopas, B., K. Kongwatananon, C. Rangdang and R. Yamashita (1988). Mangosteen sizing machine. Kasetsart Journal of Natural Sciences, Kasetsart University, Thailand 22(S):91-96.

Jong, K., B.C. Stone and E. Soepadmo (1973). Malaysian tropical forest: an underexploited genetic reservoir of edible fruit tree species. Proc. Symp. Biol. Res. and Nat. Devel: 113-121.

Kawamata, S. (1977). Studies on determining the sugar composition of fruits. Bull. Tokyo Agric. Expt. Sta. 10:53-67.

Kosiyachinda, S. (1986). Post-harvest technology of mangosteen, durian and rambutan. Kehakarn Kaset, Thailand. 19(115):37-41 (in Thai).

Krishnamurthi, S. and V.N.M. Rao (1962). Mangosteen deserves wider attention. Indian Hort. 7(1):3-4,8.

Krishnamurthi, S., V.N.M. Rao and A.A. Ravoof (1964). A note on the flowers and floral biology in mangosteen (*Garcinia mangostana* L.). S. Indian Hort. 12(3/4):99-101.

Krishnamurthi, S. and V.N.M. Rao (1965). The mangosteen, its introduction and establishment in peninsular India. In: Advances in Agricultural Sciences and their applications. Madras Agricultural Journal, Agricultural College and Research Institute, Coimbatore, India: 401-420.

Krishnan, R., M.S. Ahmad, M.Y. Ahmad and P.F. Osman (1980). Pembiakan koko secara tampang, Risalah MARDI, Malaysia (in Malay).

Lim, A.L. (1984). The embryology of *Garcinia mangostana* L. (Clusiaceae). Gardens' Bulletin, Singapore 37:93-103.

Lloyd, G. and B. McCown (1981). Commercially feasible micropropagation of mountain laurel by the use of shoot tip culture. Combined Proceedings International Plant Propagation Society 30:421-426.

Luna, J.V.U. (1984). Practical instructions for the cultivation of tropical fruits. Circula Tecnica-Emprasa de Pesquisa Agropecuaria de Bahia (Brazil) 9: (in Portuguese).

MacLeod, A.J. and N.M. Pieris (1982). Volatile flavour components of mangosteen, *Garcinia mangostana*. Phytochemistry 21(1):117-119.

Macmillan, H.F. (1935). Tropical planting and gardening. Macmillan, New York.

Marchal, J. (1972). Premières analyses foliaires du mangoustanier. Fruits 27(5):361-2.

Martin, F.W. (1980). Durian and mangosteen. In: Tropical and subtropical fruits.(eds: S. Nagy and P.E. Shaw) AVI, Westport, Connecticut: 407-414

Ministry of Health (1987). Nutrient composition of Thai foods. Ministry of Health, Thailand.

Moreuil, C. (1971). Notes brèves sur quelques espèces fruitières de la côte est de Madagascar. Fruits d'Outre Mer. 26:53-65.

Morton, J.F. (1987). Fruits of warm climates. Creative Resource Systems, North Carolina, USA:301-304.

Murashige, T. and F. Skoog (1962). A revised medium for rapid growth and bio-assays with tobacco tissue cultures. Physiologia Plantarum 15:473-497.

Murray, C. (1990). Packaging, transportation and marketing of fresh horticultural produce. Food and Agriculture Organization Report AG7/1.1. Bangkok, Thailand.

Nagy, S. and R.E. Shaw (eds.) (1980). Tropical and subtropical fruits: composition, properties and uses. AVI Publishing Co., Westport, Connecticut, USA.

Ng, F.S. and H.S. Loh (1974). Flowering to fruiting period of Malaysian trees. Malay. Forest 37:127-132.

Nieuwolt, S., M. Z. Ghazalli and B. Gopinanthan (1982). Agroecological regions in Peninsular Malaysia. MARDI, Serdang.

Oberti, B. (1968). Le mangoustanier au Nicaragua. IFAC Document 25, R.A. 68

Ochse, J.J. (1931). Fruit and fruit culture in the Dutch East Indies. Kolff. Djakarta, Indonesia.

Ochse, J.J., M.J. Soule, Jr., M.J. Dijkman and C. Wehlburg (1961). Tropical and subtropical agriculture Vol.1. Collier-Macmillan, London.

Oliver, G.W. (1911). The seedling inarch and nurse plant methods of propagation. Bull. US. Dep. Agric. Bur. Pl. Ind. 201.

Ong Hean Tatt (1976). Climatic changes in water balance and their effects on tropical flowering. Planter, Malaysia 52(602):174-179.

Pijpers, D., J.G. Constant and K. Jansen (1986). The complete book of fruit. Multimedia Publications, London.

Pongboonrawd, S. (1976). Foreign plants in Thailand, properties of foreign and Thai medicine. Kasembannakit, Bangkok.

Popenoe, W. (1928). The mangosteen in America. J. Hered., 19:537-545.

Popenoe, W. (1938). Manual of tropical and subtropical fruits. Macmillan, New York.

Pungsuwan, N. (1989). Quality control for mangosteen export. Kahakarnkaset, Thailand. 13(4):48-51 (in Thai).

Purseglove, J.W. (1972). Tropical crops: Dicotyledons. Longman, London.

Raman, K.R., N.V. Raman and R. Sadasivam (1971). A note on the storage behaviour of mangosteen (*Garcinia mangostana* L.). South Indian Horticulture 19(1/4):85-86.

Ramlan, M.F., T.M.M. Mahmud, B.M. Hasan and M.Z. Karim (1992). Studies on photosynthesis on young mangosteen plants grown under several growth conditions. Acta Horticulturae 321:482-489.

Richards, A.J. (1990a). Studies in *Garcinia*, dioecious tropical forest trees: agamospermy. Botanical Journal of the Linnean Society 103:233-250.

Richards, A.J. (1990b). Studies in *Garcinia*, dioecious tropical forest trees: the origin of the mangosteen (*G. mangostana* L.). Botanical Journal of the Linnean Society 103:301-308.

Samson, J.A. (1986). Tropical fruits. Longman, London.

Sastrapradja, S. (1975). Tropical fruit germplasm in South-east Asia. In: South-east Asian plant genetic resources (eds: J.T. Williams, C.H. Lamoureux and N. Walijarni-Soetjipto):33-46. IBPGR/SEAMO/ BIOTROP/LIPI, Bogor, Indonesia.

Sedgley, M. and A.R. Griffin (1989). Sexual reproduction of tree crops. Academic Press, London.

Sen, A.K., K.K. Sarker, P.C. Mazumder, N. Banerji, R. Uusvuori, and T.A. Hase, (1980). Phytochem. 19:2223-35.

Sen, A.K., K.K. Sarker, P.C. Mazumder, N. Banerji, R. Uusvuori and T.A. Hase (1982). Phytochem. 21:1747-50.

Sharif Achmad, Z. A. Mohamed, C. S. Teck, Wan Hamidah, Wan Hussein (1983). Past, present and suggested future research on mangosteen with examples of research and production in Malaysia. In: Promoting research in tropical fruits. (ed: A. Schirmer), DSE, Germany.

Siddappa, G.S. and S.S. Bhatia (1954). Preservation of mangosteen (*Garcinia mangostana* L.) Bull. Centr. Food Res. Inst. Mysore, India 3:296-297.

Singh, K.G. (1973). A check list of hosts and diseases in Peninsular Malaysia. Min. Agr. and Fish. Div. Agr. Bull: 132.

Sosrodiharjo, S. (1980). Picking maturity of mangosteen. Buletin Penelitian Hortikulture 8(4):11-17. (In Indonesian).

Srivasta, H.C., K.K. Singh and P.B. Mathur (1962). Refrigerated storage of mangosteen (*Garcinia mangostana*). Food Science (Mysore) 11:226-228.

Stephens, S.E. (1935). Some tropical fruits. I. The mangosteen. Qld. Agric. J., Australia. 44:346-348.

Sunaryono, H. (1987) Shortening the juvenile period of mangosteen (*Garcinia mangostana*). Warta Penelitian dan Pengembangan Pertanian (Indonesia). (in Indonesian).

Sundaram, B.M., C. Gopalakrishnan, S. Subramanian, D. Shankaranarayanan, L. Kameswaran (1983). Antimicrobial activities of *Garcinia mangostana*. Planta Medica 48(1):59-60.

Terra, G.J.A. (1949). De tuinbouw in Indonesië. Gravenhage, Netherlands.

Thayer, E.F. (1961). Mangosteen. Amer. Hort. Mag. 40:299.

Tixier, P. (1955). Contribution a l'étude des *Garcinia*. Fruits d'Outre Mer. 10:209-212.

Tongdee, S.C. and A. Suwanagul (1989). Postharvest mechanical damage in mangosteen. ASEAN Food Journal 4(4):151-155.

Usher, G. (1974). A dictionary of plants used by man. Constable, London.

Vaz de, C.R. (1983). Mangosteen: a neglected tropical fruit In: Promoting research in tropical fruits. (ed: A. Schirmer) DSE, Germany.

Verheij, E.W.M. (1991). *Garcinia mangostana* L. In: Edible fruits and nuts. Plant resources of South East Asia No. 2. (eds: Verheij, E.W.M. and R.E. Coronel), PROSEA. Pudoc, Netherlands.

Visetbhakdi, N. (1988). Fruit exports. Bangkok Bank Monthly Review 29(11):466-473.

Wester, P.J. (1926). Edible *Garcinias* and possible mangosteen stocks. J. Dep. Agric., Puerto Rico, 10: 283-305.

Whitmore, T.C. (1973). *Guttiferae* In: Tree flora of Malaya (ed: T.C. Witmore). Vol.2. Longman, Kuala Lumpur, Malaysia.

Wiebel, J., E.K. Chacko and W.J.S. Downton (1992). Mangosteen (*Garcinia mangostana* L.) a potential crop for tropical northern Austraila. Acta Horticulturae 321:132-137.

Winters, H.F. (1953). The mangosteen. Fruit Var. Hort. Digest. 8(4):57-58.

Yii, Q.J. (1987). Report on mangosteen growing in Hainan. Hainan Trop. Crop Res. Inst. China.

Zabedah, M. and A. Rukayah (1988). Percambahan biji benih dan campuran tanah yang sesuai untuk pertumbuhan awal anak manggis (Seed germination and suitable soil mixture for the early growth of mangosteen seedlings) Technol. Buah-buahan, Malaysia. 4:7-12.

Zeven, A.C. and J.M.J. de Wet (1982). Dictionary of cultivated plants and their regions of diversity. PUDOC, Wageningen, Netherlands.

INDEX

FAO TECHNICAL PAPERS

FAO PLANT PRODUCTION AND PROTECTION PAPERS

1 Horticulture: a select bibliography, 1976 (E)
2 Cotton specialists and research institutions in selected countries, 1976 (E)
3 Food legumes: distribution, adaptability and biology of yield, 1977 (E F S)
4 Soybean production in the tropics, 1977 (C E F S)
4 Rev.1 Soybean production in the tropics (first revision), 1982 (E)
5 Les systèmes pastoraux sahéliens, 1977 (F)
6 Pest resistance to pesticides and crop loss assessment - Vol. 1, 1977 (E F S)
6/2 Pest resistance to pesticides and crop loss assessment - Vol. 2, 1979 (E F S)
6/3 Pest resistance to pesticides and crop loss assessment - Vol. 3, 1981 (E F S)
7 Rodent pest biology and control - Bibliography 1970-74, 1977 (E)
8 Tropical pasture seed production, 1979 (E F** S**)
9 Food legume crops: improvement and production, 1977 (E)
10 Pesticide residues in food, 1977 - Report, 1978 (E F S)
10 Rev. Pesticide residues in food 1977 - Report, 1978 (E)
10 Sup. Pesticide residues in food 1977 - Evaluations, 1978 (E)
11 Pesticide residues in food 1965-78 - Index and summary, 1978 (E F S)
12 Crop calendars, 1978 (E/F/S)
13 The use of FAO specifications for plant protection products, 1979 (E F S)
14 Guidelines for integrated control of rice insect pests, 1979 (Ar C E F S)
15 Pesticide residues in food 1978 - Report, 1979 (E F S)
15 Sup. Pesticide residues in food 1978 - Evaluations, 1979 (E)
16 Rodenticides: analyses, specifications, formulations, 1979 (E F S)
17 Agrometeorological crop monitoring and forecasting, 1979 (C E F S)
18 Guidelines for integrated control of maize pests, 1979 (C E)
19 Elements of integrated control of sorghum pests, 1979 (E F S)
20 Pesticide residues in food 1979 - Report, 1980 (E F S)
20 Sup. Pesticide residues in food 1979 - Evaluations, 1980 (E)
21 Recommended methods for measurement of pest resistance to pesticides, 1980 (E F)
22 China: multiple cropping and related crop production technology, 1980 (E)
23 China: development of olive production, 1980 (E)
24/1 Improvement and production of maize, sorghum and millet - Vol. 1. General principles, 1980 (E F)
24/2 Improvement and production of maize, sorghum and millet - Vol. 2. Breeding, agronomy and seed production, 1980 (E F)
25 *Prosopis tamarugo:* fodder tree for arid zones, 1981 (E F S)
26 Pesticide residues in food 1980 - Report, 1981 (E F S)
26 Sup. Pesticide residues in food 1980 - Evaluations, 1981 (E)
27 Small-scale cash crop farming in South Asia, 1981 (E)
28 Second expert consultation on environmental criteria for registration of pesticides, 1981 (E F S)
29 Sesame: status and improvement, 1981 (E)
30 Palm tissue culture, 1981 (C E)
31 An eco-climatic classification of intertropical Africa, 1981 (E)
32 Weeds in tropical crops: selected abstracts, 1981 (E)
32 Sup.1 Weeds in tropical crops: review of abstracts, 1982 (E)
33 Plant collecting and herbarium development, 1981 (E)
34 Improvement of nutritional quality of food crops, 1981 (C E)
35 Date production and protection, 1982 (Ar E)
36 El cultivo y la utilización del tarwi - *Lupinus mutabilis* Sweet, 1982 (S)
37 Pesticide residues in food 1981 - Report, 1982 (E F S)
38 Winged bean production in the tropics, 1982 (E)
39 Seeds, 1982 (E/F/S)
40 Rodent control in agriculture, 1982 (Ar C E F S)
41 Rice development and rainfed rice production, 1982 (E)
42 Pesticide residues in food 1981 - Evaluations, 1982 (E)
43 Manual on mushroom cultivation, 1983 (E F)
44 Improving weed management, 1984 (E F S)
45 Pocket computers in agrometeorology, 1983 (E)
46 Pesticide residues in food 1982 - Report, 1983 (E F S)
47 The sago palm, 1983 (E F)
48 Guidelines for integrated control of cotton pests, 1983 (Ar E F S)
49 Pesticide residues in food 1982 - Evaluations, 1983 (E)
50 International plant quarantine treatment manual, 1983 (C E)
51 Handbook on jute, 1983 (E)
52 The palmyrah palm: potential and perspectives, 1983 (E)
53/1 Selected medicinal plants, 1983 (E)
54 Manual of fumigation for insect control, 1984 (C E F S)
55 Breeding for durable disease and pest resistance, 1984 (C E)
56 Pesticide residues in food 1983 - Report, 1984 (E F S)
57 Coconut, tree of life, 1984 (E S)
58 Economic guidelines for crop pest control, 1984 (E F S)
59 Micropropagation of selected rootcrops, palms, citrus and ornamental species, 1984 (E)
60 Minimum requirements for receiving and maintaining tissue culture propagating material, 1985 (E F S)
61 Pesticide residues in food 1983 - Evaluations, 1985 (E)
62 Pesticide residues in food 1984 - Report, 1985 (E F S)
63 Manual of pest control for food security reserve grain stocks, 1985 (C E)
64 Contribution à l'écologie des aphides africains, 1985 (F)

65 Amélioration de la culture irriguée du riz des petits fermiers, 1985 (F)
66 Sesame and safflower: status and potentials, 1985 (E)
67 Pesticide residues in food 1984 – Evaluations, 1985 (E)
68 Pesticide residues in food 1985 – Report, 1986 (E F S)
69 Breeding for horizontal resistance to wheat diseases, 1986 (E)
70 Breeding for durable resistance in perennial crops, 1986 (E)
71 Technical guideline on seed potato micropropagation and multiplication, 1986 (E)
72/1 Pesticide residues in food 1985 – Evaluations – Part I: Residues, 1986 (E)
72/2 Pesticide residues in food 1985 – Evaluations – Part II: Toxicology, 1986 (E)
73 Early agrometeorological crop yield assessment, 1986 (E F S)
74 Ecology and control of perennial weeds in Latin America, 1986 (E S)
75 Technical guidelines for field variety trials, 1993 (E F S)
76 Guidelines for seed exchange and plant introduction in tropical crops, 1986 (E)
77 Pesticide residues in food 1986 – Report, 1986 (E F S)
78 Pesticide residues in food 1986 – Evaluations – Part I: Residues, 1986 (E)
78/2 Pesticide residues in food 1986 – Evaluations – Part II: Toxicology, 1987 (E)
79 Tissue culture of selected tropical fruit plants, 1987 (E)
80 Improved weed management in the Near East, 1987 (E)
81 Weed science and weed control in Southeast Asia, 1987 (E)
82 Hybrid seed production of selected cereal, oil and vegetable crops, 1987 (E)
83 Litchi cultivation, 1989 (E S)
84 Pesticide residues in food 1987 – Report, 1987 (E F S)
85 Manual on the development and use of FAO specifications for plant protection products, 1987 (E** F S)
86/1 Pesticide residues in food 1987 – Evaluations – Part I: Residues, 1988 (E)
86/2 Pesticide residues in food 1987 – Evaluations – Part II: Toxicology, 1988 (E)
87 Root and tuber crops, plantains and bananas in developing countries – challenges and opportunities, 1988 (E)
88 *Jessenia* and *Oenocarpus*: neotropical oil palms worthy of domestication, 1988 (E S)
89 Vegetable production under arid and semi-arid conditions in tropical Africa, 1988 (E F)
90 Protected cultivation in the Mediterranean climate, 1990 (E F)
91 Pastures and cattle under coconuts, 1988 (E S)
92 Pesticide residues in food 1988 – Report, 1988 (E F S)
93/1 Pesticide residues in food 1988 – Evaluations – Part I: Residues, 1988 (E)
93/2 Pesticide residues in food 1988 – Evaluations – Part II: Toxicology, 1989 (E)
94 Utilization of genetic resources: suitable approaches, agronomical evaluation and use, 1989 (E)
95 Rodent pests and their control in the Near East, 1989 (E)
96 *Striga* – Improved management in Africa, 1989 (E)
97/1 Fodders for the Near East: alfalfa, 1989 (Ar E)
97/2 Fodders for the Near East: annual medic pastures, 1989 (Ar E F)
98 An annotated bibliography on rodent research in Latin America 1960-1985, 1989 (E)
99 Pesticide residues in food 1989 – Report, 1989 (E F S)
100 Pesticide residues in food 1989 – Evaluations – Part I: Residues, 1990 (E)
100/2 Pesticide residues in food 1989 – Evaluations – Part II: Toxicology, 1990 (E)
101 Soilless culture for horticultural crop production, 1990 (E)
102 Pesticide residues in food 1990 – Report , 1990 (E F S)
103/1 Pesticide residues in food 1990 – Evaluations – Part I: Residues, 1990 (E)
104 Major weeds of the Near East, 1991 (E)
105 Fundamentos teórico-prácticos del cultivo de tejidos vegetales, 1990 (S)
106 Technical guidelines for mushroom growing in the tropics, 1990 (E)
107 *Gynandropsis gynandra* (L.) Briq. – a tropical leafy vegetable – its cultivation and utilization, 1991 (E)
108 Carambola cultivation, 1993 (E S)
109 Soil solarization, 1991 (E)
110 Potato production and consumption in developing countries, 1991 (E)
111 Pesticide residues in food 1991 – Report, 1991 (E)
112 Cocoa pest and disease management in Southeast Asia and Australasia, 1992 (E)
113/1 Pesticide residues in food 1991 – Evaluations – Part I: Residues, 1991 (E)
114 Integrated pest management for protected vegetable cultivation in the Near East, 1992 (E)
115 Olive pests and their control in the Near East, 1992 (E)
116 Pesticide residues in food 1992 – Report, 1993 (E F S)
117 Quality declared seed, 1993 (E F)
118 Pesticide residues in food 1992 – Evaluations – Part I: Residues, 1993 (E)
119 Quarantine for seed, 1993 (E)
120 Weed management for developing countries, 1993 (E)
121 Rambutan cultivation, 1993 (E)
122 Pesticide residues in food 1993 – Report, 1993 (E)
123 Rodent pest management in eastern Africa, 1994 (E)
124 Pesticide residues in food 1993 – Evaluations – Part I: Residues, 1994 (E)
125 Plant quarantine: theory and practice, 1994 (Ar)
126 Tropical root and tuber crops: production, perspectives and future prospects, 1994 (E)
127 Pesticide residues in food 1994 – Report, 1994 (E)
128 Manual on the development and use of FAO specifications for plant protection products – Fourth edition, 1995 (E)
129 Mangosteen cultivation, 1995 (E)
130 Post-harvest deterioration of cassava: constraints and prospects, 1995 (E)

Availability: April 1995

Ar – Arabic		Multil –	Multilingual
C – Chinese		*	Out of print
E – English		**	In preparation
F – French			
P – Portuguese			
S – Spanish			

The FAO Technical Papers are available through the authorized FAO Sales Agents or directly from Distribution and Sales Section, FAO, Viale delle Terme di Caracalla, 00100 Rome, Italy.

Mangosteen cultivation is a technical manual in the series prepared by the FAO Horticultural Crops Group on the cultivation of promising minor tropical fruit crops. An introductory section considers the distribution, economic importance, nutritional value and uses of mangosteen (*Garcinia mangostana* L.).

The text then deals with the plant's botanical, physiological and genetic characteristics and with its ecology. It subsequently presents technical guidelines for propagation and for cultivation of the crop in suitable environments. This updated review of the state of knowledge on this species may be equally useful to researchers, horticultural technicians and farmers.

ISBN 92-5-103459-1 ISSN 0259-2517

9 789251 034590

M-11 T1847E/1/4.95/1600